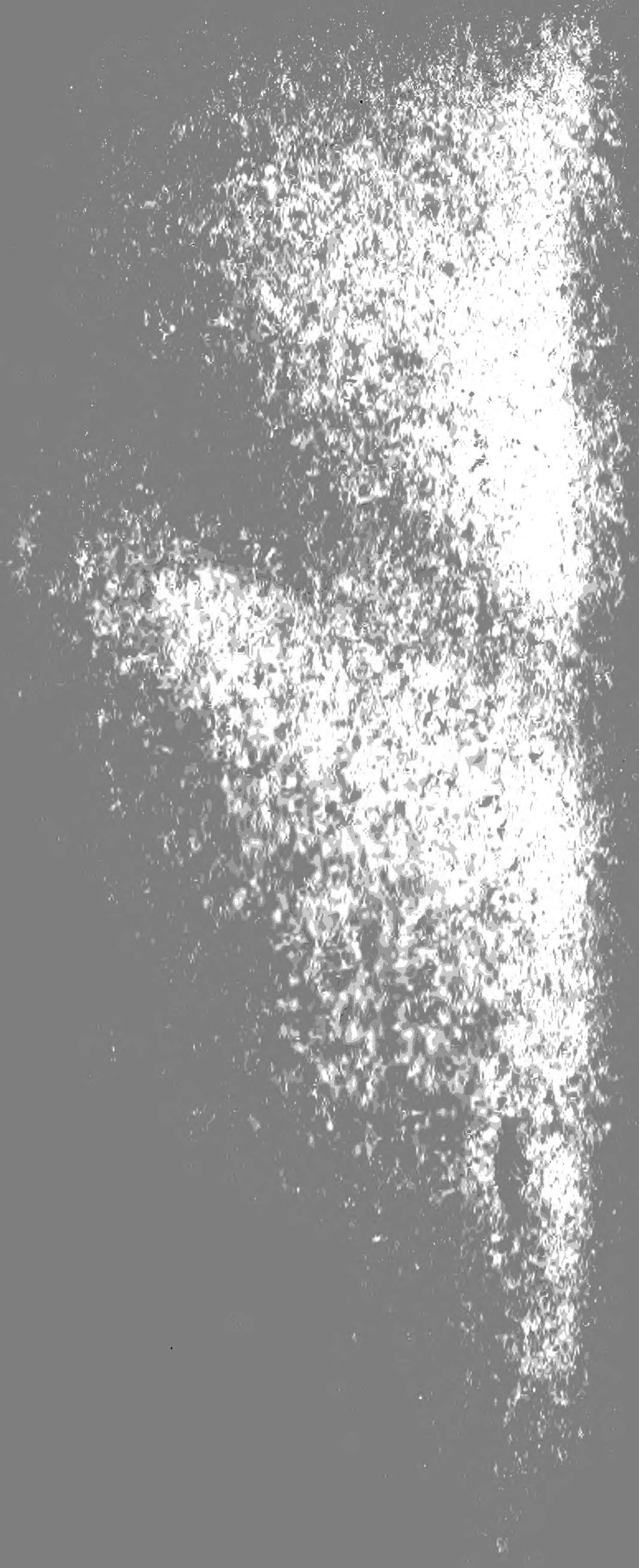

# BULLETIN

OF THE

# GEOLOGICAL SOCIETY

OF

# AMERICA



VOL. 5.

JOSEPH STANLEY-BROWN, *Editor*

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1894

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(21 plates; 43 figures.)

## PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

### Regular Publications

The Society issues a single serial publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, lists of Fellows, etc, and the latter embracing the larger papers accepted for publication. The matter is issued as soon as possible after acceptance, in covered brochures, which are at once distributed to Fellows and exchanges. The brochures are arranged for binding in annual volumes, which are elaborately indexed.

The Bulletin is sold to Fellows and the public either in full volumes or in separate brochures. The volume prices are, to Fellows, a variable amount, depending on the cost of publication; and to libraries and the public, the fixed amounts given below. The brochure price for volumes 1 and 2 are given on pages ix–xi of volume 2; the prices for the brochures of volume 3 are given on pages viii–ix of that volume.

Volume 1, covering the work of the Society from the organization, in 1888, to the end of 1889, comprises 593 + xii pages, 13 plates and 51 cuts. Price to Fellows, $4.50; to libraries, $5.00; to the public, $10.00.

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| Brochure. | Pages. | Plates. | Figures. | Price to Fellows. | Price to the Public. |
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| Pleistocene Problems in Missouri. J. E. Todd | 531–548 | .... | .... | .15 | .30 |
| Proceedings of the Sixth Annual Meeting, held at Boston, December 27, 28 and 29, 1893. H. L. Fairchild, *Secretary* | 549–665 | 20, 21 | 1 | 1.25 | 2.50 |

## Irregular Publications.

In the interest of exact bibliography, the Society takes cognizance of all publications issued either wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the Proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

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## CORRECTIONS AND INSERTIONS.

All contributors to volume 5 have been invited to send in corrections and insertions to be made in their contributions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 7, line 6 from top; the paper of Messrs Hall and Sardeson was received too late for publication in volume 5.
" 21, " 5 " " *for* "Jukes-Brown" *read* "Jukes-Browne"
" 23, " 11 " bottom; *for* "Mount Ranier" *read* "Mount Rainier"
" 39, " 11 " " *for* "cataclismic" *read* "cataclysmic"
" 73, " 8 " top; *for* "Geographical" *read* "Geological"
" 125, " 22 " " *for* "biotite, considerably" *read* "biotite considerably"
" 126, " 21 " " *for* "oridnary" *read* "ordinary"
" 129, " 4 " " *for* "above" *read* "below" [rocks"
" 136, " 4 " " *for* "any volcanic rocks" *read* "any effusive volcanic
" 145, " 6 " " *for* "at present, as, if so" *read* "at present, or, if so"
" 194, " 9 " " *for* "succeded" *read* "succeeded"
" 194, " 12 " bottom; *for* "bowlers" *read* "bowlders"
" 231, " 7 " " *for* "they rise" *read* "it rises"
" 244, " 10 " top; *after* "Devonian" *add* "and Carboniferous"
" 247, " 6 " " *for* "imestone" *read* "limestone"
" 260, " 12 " " *for* "Theorische" *read* "Theoretische"
" 265, " 20 " " *for* "minerals" *read* "mineralizers"
" 266, " 14 " " *for* "steam" *read* "stearin"
" 266, " 24 " " *for* "radical" *read* "radial"
" 266, " 29 " " *for* "entirely," *read* "entirely"
" 267, " 19 " " *for* "mutation" *read* "nutation"
" 269, " 12 " bottom; *for* "effect" *read* "affect"
" 272, " 10 " " *for* "Mortel" *read* "Mörtel"
" 273, " 20 " top; *for* "microline" *read* "microcline"
" 273, " 24 " " *for* "found" *read* "formed"
" 274, " 9 " " *for* "Wadswarth" *read* "Wadsworth"
" 275, column 5; *for* "Fürstenstem" *read* "Fürstenstein"
" 275, " 9, top line; *for* ")Bell)" *read* "(Bell)"
" 275, " 10; *for* "diabase fuses" *read* "diabase solidifies"
" 277, headline; *for* "MAGNETIC" *read* "MAGMATIC"
" 277, " insert period after "ZONES"
" 277, line 26 from top; *for* "minera lisers" *read* "mineralizers"
" 278, " 1 " " *for* "=" *read* "<"
" 278, " 6 " bottom; *for* "unradial" *read* "unequal radial"
" 280, " 17 " top; *for* "on" *read* "or"
" 288, " 21 " " *for* "decomporsed" *read* "decomposed"
" 320, " 15 " " *for* "Kemp" *read* "Kent"
" 341, " 15 " bottom; *for* "North" *read* "South"

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 5, PP. 1-38, PL. 1 NOVEMBER 7, 1893

# PROCEEDINGS OF THE FIFTH SUMMER MEETING, HELD AT MADISON, AUGUST 15 AND 16, 1893

H. L. FAIRCHILD, *Secretary*

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## SESSION OF TUESDAY MORNING, AUGUST 15

The Society met at 10 o'clock a m, in the geological lecture-room, Science Hall, University of Wisconsin; First Vice-President T. C. Chamberlin in the chair.

Professor C. R. Van Hise welcomed the Society to the city of Madison and to the University of Wisconsin. In acknowledgment of this welcome response was made by the acting President.

A communication from the President, Sir J. William Dawson, was read, expressing regret at his enforced absence from the meeting of the

Society, through illness. The scientific portion of his communication was reserved for the scientific program, and placed as the first paper upon the list.

### ELECTION OF FELLOWS

The Secretary announced as the result of the balloting for Fellows that the following persons were elected Fellows of the Society:

SANDFORD FLEMING, LL. D., Ottawa, Canada. Civil Engineer; interested especially in Pleistocene geology.

CHARLES HENRY GORDON, B. S., M. S., Evanston, Ill. Instructor in Natural History, Northwestern University; now engaged in field-work, principally in Carboniferous regions; also in special studies in stratigraphic geology and in paleontology.

CHARLES ARTHUR HOLLICK, Ph. B. Assistant in Geology, Columbia College, New York City; engaged in paleontology.

THOMAS CHESMER WESTON, Ottawa, Canada. Assistant Curator, etc, Geological Survey Department; now engaged in paleontology and ethnology.

ALBERT ALLEN WRIGHT, A. B., Ph. B., A. M. Professor of Geology, Oberlin College, Oberlin, Ohio; engaged in general geology, with special attention to lithologic geology and mineralogy.

The Secretary read a communication from the Alpine Club and an accompanying letter from Major Marshall Hall, requesting concert of action in observing and recording glacial movements and other glacial phenomena. This was accompanied by a recommendation from the Council that a committee of three be elected to report at the winter meeting of the Society. The committee was elected as follows: I. C. Russell, J. W. Spencer and Warren Upham.

In response to a circular letter of invitation transmitted to foreign geologists by the President and Secretary, several letters were presented from European geologists expressing regrets at their inability to be present at this meeting of the Society.

The President announced that the Council had determined that the other sessions of the meeting should be held on Tuesday afternoon and Tuesday evening, and on the morning and afternoon of Wednesday.

The scientific work of the meeting was declared in order, and the President announced the first paper on the printed program, which, in the absence of the author, was read by the Secretary:

## THE STUDY OF FOSSIL PLANTS

BY SIR J. WILLIAM DAWSON

It is a cause of much regret to me that the imperfect restoration of my health will prevent me from enjoying the pleasure of attending the Madison meeting of the Society. I beg, however, to extend to all my colleagues and to the visitors

from abroad who may honor the Society with their presence my most cordial regards and good wishes, and to express the hope that the meeting may be in the highest degree pleasant and profitable.

Though unable to prepare any formal paper or address, I desire to invite your attention for a few minutes to a subject to which I have given some study in recent years, more especially from the point of view of a geologist.

The study of fossil plants has until lately been comparatively neglected by geologists, in comparison with that of animal fossils. Its interest in connection with the history of life on the earth has been admitted on all sides, and much attention has been given both to the discrimination of species and to the peculiar structures of the more ancient forms of vegetation, but it has by many geologists been quietly set aside as having little bearing on the progress of their science. I propose to make a few remarks on this subject, based principally on my own experience, and preparatory perhaps to a more full treatment of the question should I be permitted to attend the winter meeting of the Society.

The two principal points in which fossil plants can aid the geologist are in the determination of geologic age and in that of climatal conditions. In regard to the former, plants have the advantage of very wide geographic distribution over the continents, and in earlier periods, when climatal distinctions were less marked, more so than at present. In this respect they correspond in some degree on the land to the distribution of the lower forms of marine life in the sea. On the other hand, they are much affected by climate, altitude and station, but scarcely more so than animal fossils. The species and generic forms of plants are, however, of long duration, and are therefore less available for nice discrimination of subdivisions of geologic formations than the higher animals. With reference to indications of change of climate, and this more especially in the later parts of the geologic series, they are of paramount value and have afforded the most satisfactory results.

If we go back to the oldest land flora certainly known, that of the Silurian and Erian or Devonian, though the plants are of strange and peculiar forms and indicative of a much greater uniformity of climate than that prevailing at present, they afford valuable marks of geologic time. I have shown that in Canada three subdivisions are indicated by fossil plants, and this with a great degree of certainty. The oldest is that of the upper beds of the Silurian and the lower Erian, characterized by the prevalence of *Psilophyton*, *Arthrostigma* and some rhizocarpean forms like *Parka*. This holds good over both America and western Europe. The second is that of the middle Erian, of which a prominent type is that of the plant beds of Saint John, New Brunswick. This is remarkably rich in ferns, and with this corresponds the not infrequent occurrence of drift stems of tree ferns even in the marine limestones and shales of the Corniferous and Hamilton groups in the United States. The rich plant beds of this horizon are apparently very limited in distribution, but wherever they can be found they will yield good geologic evidence. The upper Erian (Chemung and Catskill) shows a poorer flora, but is characterized by the ferns of the genus *Archæopteris*, and in some regions by a marvelous abundance of macrospores of *Proto-salvinia*. These three subdivisions have now been so correlated with the fossil fishes and the stratigraphy of the system that no doubt can exist as to their validity or their value in determining different horizons.

Ascending into the Carboniferous we find the same monotonous flora, indicating the prevalence of very uniform conditions over large areas, and probably a low and flat position of the continents and much carbon dioxide in the atmosphere. This

flora also, like that of the Erian, prevails from the north pole to the equator, and with some modification in the southern hemisphere. We have here also three well marked sub-floras. The oldest is characterized by lepidodendra, with imperfectly developed exogenous woody zone and short leaves of the type of *L. velthemianum*, and by cyclopterid ferns of the type which I have named *Aneimites*. The Horton series of Nova Scotia, the lower or bastard Coal Measures of the Southern states, and the Tweedian series of England and Scotland exemplify this flora, which is markedly distinct from that of the upper Erian below and that of the Millstone Grit and productive coal measures above. The central group exemplifies the culmination of the well known coal formation flora, on which no special remark need be made. Above this the Carboniferous flora dwindles into that of the Permian, described by Fontaine in the south and by Mr Bain and myself in Prince Edward island. The genus *Tylodendron* is one of its peculiar forms, as well as certain species of calamites, ferns and asterophyllites.

The older Mesozoic flora is quite distinct from that of the Carboniferous on the one hand and that of the middle Cretaceous on the other. Its subdivisions are not so well marked or so well ascertained as those of the Carboniferous, but there are certainly distinct Triassic, Jurassic and lower Cretaceous forms, quite sufficient for paleontologic distinction.

In the middle and upper Cretaceous and the Tertiary there has been much confusion, owing to want of stratigraphic distinctness of the beds holding the fossils. This difficulty is, however, rapidly being removed, and Starkie Gardner, in England, and Ward, in America, have been successfully laboring in this, while we have been doing our share in Canada. In North America, at least, there is now no difficulty in distinguishing a lower, middle and upper Cretaceous flora, besides that of the Laramie, which is more nearly related to the lower Eocene than to that of the Cretaceous, that of the Miocene, and that of the Pliocene and Pleistocene. The distinctness and yet similarities of these successive floras, their growing assimilation to those of the modern period, and the vicissitudes of physical geography and climate which they indicate are among the most remarkable facts of modern geology; and it is not saying too much to affirm that, in so far as climatal conditions are concerned, the evidence of fossil plants has done more than that of animals to elucidate these vicissitudes of the earth's later history, and that it is destined in the near future to do so still more. On this part of the subject, however, I do not propose to enter at present. It is one raising a great variety of difficult questions respecting the alternations of warm and cold climates in the northern hemisphere, and I hope to make it the subject of an address for our winter meeting.

This country has lost within a short time two distinguished paleobotanists: first Lesquereux and then Newberry—losses hard to be supplied. It is, however, gratifying to know that there are younger men ably following in their steps. The Geological Survey of the United States has just published, under the judicious editorship of Professor Knowlton, Lesquereux's last work on that most interesting flora of the Dakota group, which in Cenomanian times extended itself over North America and as far as Greenland; and for the first time established on our continent, and this in a grand and noble form, the undisputed reign of the dicotyledonous trees. To this report Lesquereux has appended an analysis of the Cretaceous floras, embodying the results of his long experience, and tracing the fortunes of the several genera, so far as known, from their earliest appearance to the modern time,

This essay deserves the careful study of every one interested in the history of life on our planet.

It is well that the Geological Survey of the United States can give to the world such works and can afford a place on its staff and in its laboratories to this important subject. It is to be hoped that it may do this to a still greater extent, for however the study of fossil plants may be advanced by the zeal of independent collectors and students, it requires a national nucleus and means for adequate publication and distribution of its results, and for the safe keeping and proper arrangement of those specimens, often so rare, valuable and fragile, which exhibit to the eye the history of plant life from the old Paleozoic times.

Remarks upon the matter of the President's communication were made by C. D. Walcott, who stated that the uncompleted work of Professor J. S. Newberry would be prepared for publication by Dr Arthur Hollick, and that paleobotanic work was receiving full attention in the United States Geological Survey and National Museum; Professor Lester F. Ward and Professor F. H. Knowlton being engaged upon the paleobotany of the Mesozoic and Cenozoic strata, and Mr David White upon the Paleozoic flora.

The second paper read was—

### ORIGIN OF THE PENNSYLVANIA ANTHRACITE

BY J. J. STEVENSON

This paper will be found printed in full in succeeding pages of this volume.

The third and concluding paper of the morning session was as follows:

### THE SUCCESSION IN THE MARQUETTE IRON DISTRICT OF MICHIGAN

BY C. R. VAN HISE

[*Abstract*]

As a result of the detailed mapping of the Marquette iron-bearing district of Michigan by the Lake Superior division of the United States Geological Survey the following succession has been found to obtain in the iron-producing part of the area:

The oldest group of the region is the Basement Complex, consisting of granites, gneisses, various green schists and greenstone-conglomerates. The latter rocks appear to be surface volcanics, in part lavas and in part tuffs. The green schists, as well as the mica-schists, hornblende-schists and gneisses, are intruded in the most intricate way by the granite and gneissoid granite. Many of the laminated rocks have been traced into massive phases, so that it is known that many of them are of igneous origin. On the other hand, it has not been possible as yet to show

that any are sedimentary, although it is not asserted that such rocks do not exist within the Basement Complex.

Following the Basement Complex unconformably is the Lower Marquette series. At the base of this series is a conglomerate and quartzite formation, usually thin, and upon this rests an iron-bearing formation, so called because within it occur ore-bodies. The change from the quartzite to the iron-bearing formation is usually gradual, and before the typical phases of the formation appear there are in places several alternations of fragmental and non-fragmental material. The iron-bearing formation comprises many varieties of rocks, actinolite-magnetite-schists, ferruginous chert and jasper, however, being the most prevalent, but ferro-dolomite is also present.

Resting unconformably on the Lower Marquette series or upon the Basement Complex is the Upper Marquette series. Looked at broadly, this is a great shale, mica-slate and mica-schist formation. However, at its base at many places are quartzites and conglomerates, the character of which depends upon the immediately subjacent rocks. Where the inferior rock chances to be the iron-bearing formation of the Lower Marquette, the detritus forms a recomposed iron-formation, and when secondary concentration has also occurred, this may carry ore-bodies. The Upper Marquette slate contains another iron-bearing horizon, which is situated several hundred to one thousand feet from its base. The phases of rock constituting this formation are similar to those of the iron-bearing formation in the Lower Marquette, although jasper is not so plentiful, and cherty ferro-dolomite is more abundant.

At the east end of the Marquette district appears an area of cherty quartzites, slates and cherty limestones, to which the term Mesnard series has been applied by the Michigan state survey. This series is lithologically very different from the Lower Marquette or Upper Marquette series as developed in the iron-bearing district to the westward. Its position has not yet been positively determined. It is possibly a downward continuation of the Upper Marquette series, and also possibly occupies a position unconformably between the Lower Marquette and Upper Marquette series as they exist to the west. The succession in the Mesnardarea in its most typical development comprises in ascending order (1) a lower quartzite, at the bottom of which is frequently a basal conglomerate; (2) a formation consisting of dolomite interstratified with slates and quartzites, often cherty, and (3) an upper quartzite often similar to the belts of this rock interstratified with the dolomite.

Included within the Marquette series are great intrusive dikes and bosses of altered diabase. Their intrusion is in many places the cause of the minor folding. Also in the Upper Marquette district is an extensive area of contemporaneous volcanics, largely tuffs, running from north of the Saginaw and Goodrich mines to Champion. The greatest width of this volcanic belt and the locus of the ancient volcano was southeast of Clarksburg. In passing east or west from this center more and more of water-deposited sediments appear mingled with the volcanic débris, until the rocks pass into the ordinary sediments of the region.

To the above succession and the separating unconformities both the United States and the Michigan geological surveys are agreed. The latter survey has, however, recently announced that the Lower Marquette and the Upper Marquette are each divisible into two series by minor unconformities; the first into Republic and Mesnard, the second into Holyoke and Negaunee. This order places the Mesnard in the second of the two possible places above suggested. The evidence upon which these new subdivisions are based has as yet not been published.

## Session of Tuesday Afternoon, August 15

The Society was called to order by Vice-President Stevenson, at 2 o'clock, and the following paper was read by F. W. Sardeson:

### THE MAGNESIAN SERIES OF THE NORTHWESTERN STATES

BY C. W. HALL AND F. W. SARDESON

This paper will be found printed in full in the succeeding pages of this volume.

The three following papers, by the same author, were read in succession without discussion:

### A NEW SPECIES OF *DINICHTHYS*

### A NEW *CLADODUS* FROM THE CLEVELAND SHALE

### A REMARKABLE FOSSIL JAW FROM THE CLEVELAND SHALE

BY E. W. CLAYPOLE

The three following papers were read in succession and discussed as a whole:

### LIMITS OF THE GLACIATED AREA IN NEW JERSEY

BY A. A. WRIGHT

*Contents*



#### Introduction.

A year ago, at the Rochester meeting of the American Association for the Advancement of Science, I presented a paper on "Extramorainic Drift in New Jersey," in which the endeavor was made to distinguish between the true glacial deposits and those which had suffered some secondary transportation by water or floating ice. The area studied was principally the western part of the state, from Delaware river about Belvidere and Easton eastward to about Oxford Furnace, Washington and High Bridge, the latter on the southern branch of Raritan river.

During the present season I have had the opportunity of extending observations eastward and southward. The additional facts now presented sustain most of the conclusions of the previous paper, but modify some, and, as I trust, will be found an advance in the endeavor to locate the southern limit of the earlier extension of the ice-sheet. A part of this field-work this year, as last, was done in company with Professor G. F. Wright.

### Character of the glacial Material.

The area south of the moraine presents great geologic and topographic diversity, and as a result the glacial deposits in this area exhibit a great variety both as to their lithologic constitution and as to their structural arrangement. Lithologically we have in place Hudson river slates and shales, Siluro-Cambrian limestones, Cambrian quartzites and Archean gneisses, which, although they exist also in the regions north of the moraine, are found in place south of the moraine and enter conspicuously into the extramorainic deposits. Beyond these we find the southernmost glacial deposits spread out upon the red Triassic formation, and in such cases the Trias has contributed richly of its varied elements—shales, sandstones and quartzites; the latter from its conglomeratic layers. For foreign elements we find bowlders representing the Oriskany, the Clinton, the Medina and Oneida, all of which exist in place in the region of Kittatinny mountain, upon the extreme northern border of the state, while the Green Pond mountain series lies at a less distance north of the moraine. Doubtless, also, some of the erratics are to be ascribed to the Laurentian area of the north. While all of these elements may enter into the composition of a deposit, it is still by the recognition of the few that may be scattered upon the surface of a region that the path of the ice is principally traced.

### Topography of the Region and its Influence on Glaciation.

The topography of the region also is sufficiently varied to beget great diversity in the thickness and extent of the true glacial deposits. On the west there are highland ridges which run diagonally to the principal direction of ice-flow, thus deflecting the ice-currents and affecting the position and the thickness of the deposits. Further east there are several trap-ridges which similarly affected and limited the ice-flow. Even the smaller preglacial valleys of erosion, which constituted the finer features of the surface configuration, are sometimes seen to have controlled the local thickness of deposits, while postglacial erosion, however great or small this may be, has added its effect in the same direction. This great variety of aspects which the drift presents, while it adds interest to the task, adds also some difficulties which are not everywhere encountered, with a resulting variety of views on the part of different observers.

### Determination of the boundary Line.

The region where the limit of the ice-flow can be most distinctly seen is perhaps neither on the eastern nor on the western border of the state, but nearer the center. Over the tolerably level plain west of Somerville and south of White House, where the rock in place is a rather uniform Triassic shale, there are several points where the distribution of northern material ceases abruptly. One of the most

accessible and satisfactory of these is situated one mile south of White House station, in Hunterdon county. There is here a fine deposit of red till, exposed to a depth of six or eight feet, containing pebbles of gneiss, quartzite, etc, from four inches in diameter down, while other fragments of similar rock up to a size of two and three feet are seen along the road. This deposit extends east and west, in a gentle swell, for more than a mile. A trifle further southward, at Drea Hook school-house, the last of the northern pebbles are seen scattered thinly over the fields and quite small in size. Southward from this point for a distance of at least two miles the country is entirely destitute of pebbles of every sort. The fields are clean and smooth and the shale in place frequently comes close to the surface. On the other hand, northward from this point for five miles through White House, Potterstown and Lamington, and thence eastward through Greater Cross-roads to Pluckamin, all upon the same Triassic area, there is to be found plenty of northern material, such as Green Pond mountain conglomerates, Kittatinny mountain quartzites and conglomerates, gneisses of various sorts, black flint, white quartz and so on.

Several other points in this vicinity were determined as definitely as that at Drea Hook. One mile southeast of Drea Hook a similar crossing of the border showed similar appearances. Still farther east the same sharp contrast occurs one mile north of Readington, and again about two miles east of Readington. In all of these cases the foreign material is distributed in such positions with reference to the topography as to warrant the belief that land-ice was the distributing agent.

Drawing a line through the points just mentioned, we find that it runs from the vicinity of the junction of the northern and southern branches of Raritan river with a northwesterly course to the eastern flank of the trap-ridge called Cushetunk mountain. This curved ridge, rising 400 or 500 feet above the surrounding country, apparently acted as a barrier against which the margin of the ice abutted, but which it did not override. Northern bowlders are found plentifully around its northern base, but not upon the southern. For example, in the railroad cut a mile west of White House station there is a deposit of till eighteen inches deep with northern pebbles up to a size of six inches. Upon examining the northern flank of the ridge up to 50 or 100 feet nothing but the local trap could be detected. At the town of Lebanon, on the northern base of the mountain, there is a good depth of till with northern bowlders. At Annandale, two miles farther westward, there are large fragments of quartzite and of Green Pond mountain conglomerate up to a length of two and a half feet. On the western foot of the mountain, at Allerville, four miles or more south of High Bridge, northern material is quite abundant, but it disappears a short distance south of this place, and for a mile or more beyond nothing foreign is found. An examination of Round valley, which lies within the horseshoe curve of Cushetunk mountain, revealed no evidence of its having been occupied by ice.

The country west of Cushetunk mountain lies somewhat higher than that on the east, and is more deeply sculptured by erosion, yet a number of points upon the boundary of glaciation seemed to be satisfactorily made out here. The underlying rock is Triassic, and it would seem that all foreign materials might easily be distinguished in contrast with it; but over most of the region it is the conglomeratic layers of the Trias that are exposed, and which contain pebbles of northern quartzites, conglomerates and probably other types of rock brought into the region

in Triassic times. These rounded pebbles have been weathered out of their unstable red matrix in great numbers, probably in both preglacial and postglacial times. They reach a size of three inches commonly, but still there are plenty of 6 and 12 inches and some of 15 inches. Not infrequently in the vicinity of streams we find these pebbles redeposited with clay and sand in unstratified masses closely resembling glacial till. There are other deposits of these same materials, however, which are doubtless glacial, and some of them may be characterized by angular fragments of gneiss from the mountains northward, which have never been imbedded in the Triassic conglomerate. On account of the difficulties just described the points upon the boundary which are given west of Cushetunk mountain may not have been determined with entire precision, but they are believed to be nearly correct.

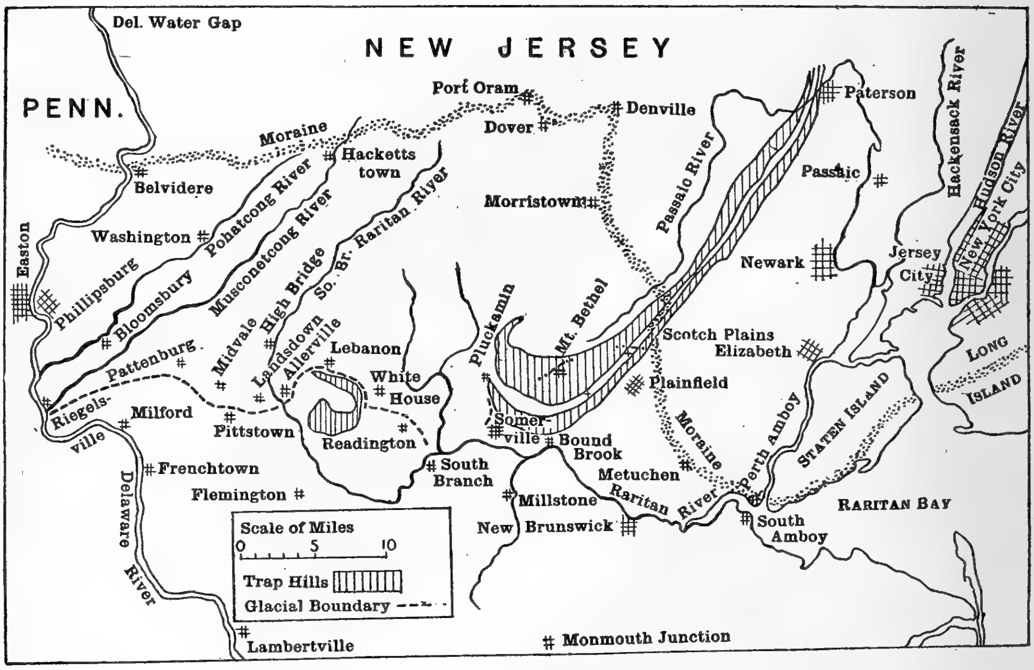


FIGURE 1.—*Map showing Limits of the glaciated Area in New Jersey.*

The first point is one-half mile south of Allerville; the second is a mile west of the first and a mile east of Landsdown; the third is at Sidney, a mile southwest of Landsdown; the fourth is at King's mill or Kingstown, and includes the hills north of Pittstown, but excludes those to the southeast and southwest of Pittstown; the fifth and sixth are about a mile south and southwest respectively of Midvale. This last station is at an altitude of 600 feet above tide, and, although still upon the Triassic, is not greatly lower than some of the passes upon the Archean ridge of Musconetcong mountain. The line doubtless passes south of Pattenburg and north of Little York, crosses the Musconetcong ridge at the altitude of 760 feet southwest of Bloomsbury, lies high upon the northwestern flank of the Musconetcong south of Hughesville, and reaches the Delaware river in the vicinity of Riegelsville. More detailed work may yet be profitably done in determining the distribution of the drift upon Musconetcong mountain west of Pattenburg.

### THE ALTITUDE OF THE DETERMINED POINTS.

The altitude of the points upon this boundary line decreases from west to east. Upon Musconetcong mountain it is 760 feet; southwest of Midvale it is 600 feet; north of Pittstown it is 460 feet; at Sidney, 360 feet; around the base of Cushetunk mountain it is 260 feet, and at Readington, 180 feet. Further east on this line it is impossible, from any observations yet made, to locate the boundary. The land near the Raritan is mostly between 50 and 100 feet above tide, and although there is plenty of foreign material lying upon the Triassic base, the possibility and the strong probability of its having been transported by other agencies than land-ice will force itself upon the mind of any observer. To the eastward and southward from South Branch there is encountered at all levels up to 125 or even 140 feet pebbles of yellow and white quartz, well rounded and about an inch in diameter. They are scattered rather thinly over the fields from South Branch to New Brunswick and from Somerville southward. On the low grounds along streams they may be found gathered, with sand, to a thickness of several feet. These pebbles plainly do not come from the north, but as plainly they resemble the gravel that to the southeastward lies five to fifteen feet thick upon the Cretaceous belt, extending from South Amboy to Trenton. They seem to imply a submergence, accompanied by water transportation from the southeast.

Associated with these yellow pebbles in many places there are larger ones, up to three inches, of white sandstone, well rounded and weathered to a buff or brown exterior. True quartzite pebbles of similar appearance also occur, and, beside all these, larger specimens of from 6 to 24 inches, especially of sandstones and quartzites, are irregularly scattered over a great area from Metuchen southwestward. They may have been carried by floating ice.

There is some evidence that this lobe of the ice-sheet never extended far into the country south of the Raritan, on account of the barrier presented by the trap-ridges called Watchung mountain or First and Second mountains. First mountain is about 500 feet high and Second mountain about 600. At the base of First mountain, directly north of Somerville and above the 140-foot contour, there are erratics which I think were deposited by land-ice. They consist of gneiss, quartzite, conglomerate, sandstone and trap, the latter the most abundant of all. Northern bowlders are also abundant at Pluckamin, on the western margin of the trap-hills, but eastward of Somerville and northward of Bound Brook none of these were detected; also, careful search upon the summit of the ridge north of Somerville and west of Plainfield has failed to show anything but trap. The valley between the two mountains, from Washingtonville to Warrenville, is likewise destitute, but there is plenty of northern material from Mount Bethel to Liberty Corners at the general level of 250 feet. From these facts it seems probable that the ice-sheet was never sufficiently powerful to override these trap-ridges in their southernmost extension, and we must look northward rather than southward for the true limit of the glaciated area.

### PARALLELISM OF GLACIAL BOUNDARY AND MORAINE.

The glacial boundary as thus far described will naturally be compared in position with that part of the moraine which lies north of it. The general parallelism of the two lines is apparent. The average distance between them is about 17 miles,

with a maximum of perhaps 20. While both lines are visibly deflected by the elevations of the land over which they pass, it is seen that the boundary is much the more sensitive of the two to these variations in altitude. The moraine rises from 300 feet at Belvidere, on Delaware river, to 960 feet at Budd's Lake, on Musconetcong mountain, beyond which point it descends. The boundary rises from the low ground at Riegelsville on the river to 760 feet on Musconetcong mountain, beyond which it descends; but at two different points we find its margin indented by trap-ridges of much less altitude than these maximum elevations. This fact seems to indicate that the southern margin of the ice was comparatively thin.

### Duration and Efficiency of the glacial Ice.

Some additional facts enumerated below seem to show that the work of the ice in this extramorainic area was relatively brief and not very powerful:

1. Its brevity is indicated by its failure to produce well marked morainal lines. While an exceedingly slow and uniform advance and a retreat of the same character may be conceivable, yet the chances would be that if the ice covered the area for any considerable length of time morainal lines would be developed.

2. There are some districts where the signs of glaciation are exceedingly scanty, where foreign bowlders or rounded bowlders or striated bowlders can scarcely be found. An instance in point is the region north of High Bridge, where for several miles no sure signs of glaciation were detected. The angular gneiss blocks which monopolize the surface are still resting on a gneiss basis, as if never disturbed; and yet we now know from other sources that the whole must have been covered with ice. It is hardly probable that postglacial erosion, however long continued, could wholly remove foreign bowlders from any district over which they had once been spread.

3. Many of the till deposits, especially those farther from the moraine, are composed largely of local material; that is, material which has not been carried very far. Is not this, in this case, a sign of the evanescent character of the glaciation? The first work of an invading ice-sheet will of necessity be that of pushing forward the local materials loosened by previous disintegration. If the advancing margin of the ice-sheet is formed, as is probable, from local snowfall rather than from the onward moving ice that was compacted far northward, the foreign material will be somewhat tardy in its arrival. In any case, the longer the glaciation continues the greater will be the quantity, if not the proportion, of foreign material. It is perhaps true that the majority of till deposits contain in the aggregate a greater amount of local than of foreign material, yet the vivid impression left upon one after studying the southern deposits in New Jersey is that the till responds very quickly to any change in the underlying rock, and that nearly all the erratics might have been obtained from latitudes not higher than those covered by the state of New Jersey itself. Comparatively few have to be referred to regions north of the Mohawk or of the Saint Lawrence.

### Lobes of the New Jersey Moraine.

The moraine in New Jersey may be naturally divided into two portions:

1. That which was formed by the Delaware lobe of the ice-sheet in the western part of the state.

2. That formed by the Hudson lobe in the eastern part.

The two parts join at Denville, where the moraine is seen to make a bend at right angles. From the very curve of the eastern part it is evident that a powerful current of ice was poured down the Hudson River region during the period of its formation, carrying the moraine as far as Perth Amboy, which is fully 27 miles south of Denville.

### Southeastern Limit of the glacial Ice.

The question at once arises whether, during the earlier period of maximum glaciation, the ice extended as far south of the Hudson lobe as it did south of the Delaware lobe. This problem is as yet unsolved. Although many blocks of northern gneiss and trap have been carried across Raritan river, and although white sandstones, conglomerates and quartzites, some of them three feet long, have been carried at least 15 miles southwestward from Perth Amboy, many of which were, as I think, derived from the Hudson river ice-flow, yet, so far as I have had opportunity to observe, they all lie on low ground and are associated with the yellow quartz-pebbles to which I have previously referred. The suspicion therefore obtains that they were transported by floating ice.

In the absence of the author the next paper was read by A. A. Wright:

## SOUTH MOUNTAIN GLACIATION

BY EDWARD H. WILLIAMS, JUNIOR

The region studied and concerning which this preliminary note is written is bounded on the north by South mountain just back of South Bethlehem, Pennsylvania, and on the south by a spur of the same range south of Center valley, Pennsylvania. Its eastern edge is on a line through Leithsville and Hellertown, and its western limit is a mile west of Seidersville. It occupies a space three inches from north to south and two in the other direction on the colored map of Lehigh and Northampton counties in Report of Progress, $D^3$, volume i, of the Second Geological Survey of Pennsylvania. An examination of maps 2 and 3 of the Durham and Reading hills, in the same volume, will show that the greater part of the area lies in the Saucon valley, which is landlocked to the south below 400 feet above tide, and which drains into the Lehigh valley at Shimersville by means of Saucon creek.

The valley is completely surrounded by hills of the South mountain gneiss, which have a narrow belt of Potsdam about them, while the central part is Siluro-Cambrian limestone, which has a trend northeast and southwest, and parallel to the trend of the range. The gneiss is generally syenitic in this area, but varies from acid to basic. The limestone readily decomposes to a clay, and in so doing develops a finely laminated structure. The Potsdam is a quartzite, with conchoidal fracture, and the latter is due partly to pressure, but generally to concentric aggregation about the original grains of the sandstone. It can be usually detected when weathered, but when this is extreme it simulates Medina, so that care is necessary in determining very much decomposed specimens of both these formations.

The discussion as to whether ice ever came as far south as Bethlehem induced the writer to put the postgraduates in mining engineering upon this part of the country for their geological survey, and, to make the matter sufficiently easy of

determination, it was decided to take for criteria Oriskany pebbles and bowlders, as that formation is generally fossiliferous along its outcrops to the north, and is so different from the Potsdam as to be readily distinguished from it at all stages of weathering, even when destitute of fossils. The presence of this rock would be an evidence of transportation, and when higher than 450 feet above tide (the level of the Columbia formation) would be evidence of the presence of ice or of the former occupancy of the region by Oriskany. The latter condition is so evidently impossible, when the position of the outcrops is studied, that it would be safe to attribute to ice the presence of such finds, especially if water-worn or glaciated.

The north side of the South mountain is deeply weathered, and in a cutting for the South Bethlehem reservoir extends over 20 feet below the surface. It is seldom that the gneiss is found at the surface in place. On this side of the mountain there were few evidences of transportation found, but these extended to the height of 600 feet above tide. Dropping the work on this side, the south side was examined, and there large masses of Oriskany were found, as well as typical masses of Oneida conglomerate. These were found mixed with Potsdam and gneiss as far south as a line through the second railroad cut south of Bingen station to the house of Captain Eudy near the most northern of the zinc mines at Friedensville, and south of this line nothing of the kind has thus far been found. On the contrary, the surface is generally free from everything but the rocks of the formation lying beneath and exhibits these rocks in more or less weathered conditions. North of this line four lines of rocks, more or less continuous, were found that were generally parallel to one another. The second from the south has been traced from the hill just north of Leithsville to the top of the elevation one and one-half miles west of Seidersville, where the barometer shows over 700 feet above tide. In these lines there are stones of all sizes, from small pebbles to bowlders several feet long, and in some places Oriskany is abundant.

This work is to be continued next fall, when an attempt will be made to trace the fringe over the mountain to the Lehigh valley. As it is, however, but 10 feet thick at best in the valleys, it may be impossible to do this in a satisfactory manner. This preliminary notice is to call attention to the fact that the area of direct glaciation is extended 22 miles to the southward of the great moraine—this is, about the distance of the Pattenburg, New Jersey, deposits from the same—and that a line through the New Jersey places extended to the points studied would be parallel to the great moraine. As the Saucon is a closed valley to the south, it is proposed to see if any evidences are left of beaches in the small lake formed when the ice shut up the northern opening. This will require a more careful survey than has thus far been attempted.

Finally, there has been found a patch of Potsdam on the mountain back of Seidersville, extending from a point about 150 feet east of the road to Bethlehem for a quarter of a mile eastward and at a height of 640 feet above tide. This shows that the outcrop, as marked on the map, must be revised.

Since writing the above it has been possible to put a few more days upon the field to settle the following points:

1. When the ice crossed the range on the road from Bethlehem to Emaus it removed the old soil and the undecomposed gneiss is now within a few inches of the surface. The covering seems to be foreign, as a few flakes of quartzite were found in it. The lower flanks of the same spur at the new South Bethlehem reservoirs show over 20 feet of decomposed gneiss.

2. A tongue of the glacier went over the Triassic hill south of Leithsville (how far over is not known) at an elevation of 980 feet above tide. This tongue came through the gap made by the opening of the Saucon valley into the Lehigh valley and crossed transversely the Saucon-Durham divide.

3. There are at least 15 feet of glacial gravel on the Lehigh-Schuylkill divide at Topton, Pennsylvania, at 490 feet above tide. This gives the origin of all glaciated matter in the Schuylkill valley in the Lehigh region.

4. A section at West Bethlehem gives at least 12 feet of red clay with bowlders (called provisionally "bowlder-clay"). This exists universally to the north of the South Mountain range, near Bethlehem, below a level of 440 feet above tide. It may have been deposited higher, but the red clay from decomposed gneiss is so similar in color that the two can be distinguished only by the foreign stones, and these are not always present. Under this clay come at least 22 feet of sandy gravel ("plunge and flow" structure), which rest on the scraped surface of the limestone. The sequence is: (*a*) glacial erosion; (*b*) deposit of gravel; (*c*) deposit of bowlder-clay. South of the mountain in the Saucon valley we do not find the bowlder-clay. This shows no flow up and through that valley when the clay was forming to the north.

5. The moraine-stuff consists of local angular fragments, much decomposed and oxidized, mixed with water-worn and sometimes striated foreign rock (trap, Oneida, Medina, Clinton, Oriskany, etc.), with polished surface; oxidation extending from a few lines to one-half inch from the surface, while the interior is generally fresh, except where the specimen is highly porous. This represents old local surface material that has been scraped and pushed ahead, mixed with recent foreign material taken from a river bed. As the glacier crossed the Lehigh at nearly a right angle at Bethlehem, and as the head-waters of that stream were generally free from ice, we can see that the portion of the river that escaped subglacially left its rocks, gravel and sands to be caught by the glacier and carried upon and over the mountains. Sandy and gravelly till is found at all elevations up to 980 feet above tide, and of all depths up to 30 feet.

6. From Allentown to Easton the glacier retreated *down* the Lehigh valley. The plunge and flow gravels were probably deposited as the river made its subglacial plunge, and the bowlder-clays when the river was dammed by the choking of its subglacial channel. A lake would be formed of the Lehigh valley, with slight drainage subglacially, but with its main outlet over the Lehigh-Schuylkill divide, which is now covered with glaciated material to a considerable depth. This divide is about four miles wide at the 500-foot contour line.

The conclusions from the above are:

1. That the general parallelism between the extreme line of glaciation and that of the great moraine indicates an impetus from a common center.

2. That the exposed gneiss on the mountain-top and fresh nature of the foreign material shows a recent date to that impetus.

3. That coming from a common origin and by a recent impetus, we are justified in calling the recently found evidence a "fringe" of the great moraine which was formed at the retreat of the same glacier that caused the "fringe."

4. That until the ice had retreated north of the mouth of the Lehigh there was an extensive discharge into the Schuylkill valley.*

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*See maps in Report of Progress, D3, Atlas to vols. 1 and 2, Second Geological Survey of Pennsylvania.

The third paper was:

## EXTRAMORAINIC DRIFT IN NEW JERSEY

BY G. FREDERICK WRIGHT

In the discussion of the three foregoing papers remarks were made as follows:

T. C. Chamberlin:

There is ground for congratulation in the large advance made by these papers toward harmonious views concerning the extramorainic drift of the Delaware region. A year ago the Professors Wright stoutly contended that a portion of the drift now classified by them as glacial drift was of a residuary or other origin, and vigorously antagonized the position previously taken by Professor Salisbury, who contended that these formations were true glacial deposits. The maps now presented by the Professors Wright include the localities of High Bridge, Pattenburg and others, which were specifically urged by Professor Salisbury as glacial formations, a view specifically opposed by the Professors Wright. The present mapping includes all the localities that Professor Salisbury insisted were unquestionably of glacial origin. There were certain other localities concerning which he reserved opinion, and which are now regarded by all parties as requiring further investigation. So far, then, as the question of the extension of true glacial deposits beyond the Belvedere moraine, there is substantial harmony. There remain two points of difference: the first respecting the age of the extramorainic drift, and the second relating to the connection and correlation of the Trenton gravels. Concerning the age of the extramorainic drift, I think that a contribution has also been made to the contention that it was much older than the Belvedere morine in the very fact that the Professors Wright previously denied its glacial character at such localities as High Bridge and Pattenburg, where it is thick and well exposed by railway cuttings. The drift of the Belvedere moraine and that which lies north of it is obviously very fresh and is very distinctly characterized as glacial. If the drift outside of the moraine had not been very much older and its characteristics had not been obscured by its age or by its different method of formation, they could hardly be supposed to have failed to recognize its glacial origin; nor could they be supposed to have attributed it to residuary origin, because both residuary material and residuary topography take on the characteristics of age from their very nature. As to the second point, I venture to express the opinion that Professor G. F. Wright's correlation of the Trenton gravel will prove to be erroneous.

Warren Upham:

On Long island an advance of the ice-sheet six miles south of the outermost terminal moraine is shown by the esker series forming the Manetto and Pine hills, and by a second esker a few miles farther east, called the Halfway Hollow hills.* These probably represent the same stage of ice-advance as the drift-fringe south of the moraine in New Jersey and Pennsylvania. The fully oxidized condition of the extramorainic drift seems attributable to its derivation chiefly from preglacial re-

*Am. Jour. of Science, August, 1879.

sidual clay and alluvium and weathering rock-cliffs, such as are found in the Wisconsin driftless area and south of the glacial boundary. The smooth contour of this outer drift, as compared with the hilly and knolly moraine and mostly quite uneven drift-surface from thence northward, seems due to less energetic glacial action when the ice-sheet was being accumulated, and reached farther than during its recession, when its rapid marginal melting probably gave a much steeper frontal slope, with stronger glacial currents. Any slight halt or re-advance of the ice, produced by a series of somewhat colder years and heavier snowfall than usual, would then be marked by a moraine. Since the moraines seldom are well developed on the extreme boundary of the drift, it seems better to call them marginal or retreatal moraines, rather than terminal, although at the time of its formation each was at the receding termination of the ice-sheet.

Frank Leverett:

The explanation and diagram given by Mr Upham to show his conception of the origin of the "fringe" on Long island does not seem a satisfactory explanation for the more western field between the Alleghany mountains and the Missouri river. The drift outside the moraine in that region bears evidence in the degree of surface oxidation and erosion of a great lapse of time between its deposition and the formation of the moraine which seems to be the correlative of the Long Island moraine.

W J McGee:

The excellent communication by Professor A. A. Wright is an especially gratifying presentation of facts and inferences relating to the region described. As is well known to the Society, the phenomena of the region has given rise to certain differences of opinion, and diverse opinions have been expressed at earlier meetings, notably the last summer meeting at Rochester.

Even before the institution of this Society certain superficial deposits of northern New Jersey, specifically those flanking Delaware river, were correlated with the early Pleistocene Columbia formation, and from the sum of the phenomena of this formation the existence of ancient glacial deposits in or not far north of the region was inferred, though the ice-laid deposits were not actually observed. Subsequently a detailed official survey of the region was undertaken by Professor R. D. Salisbury, under the joint auspices of the United States Geological Survey and the State Survey of New Jersey, and at the summer meeting of the Society in Washington (in 1891) Professor Salisbury announced the discovery of old glacial deposits many miles outside of the terminal moraine at different points in northern New Jersey. Later studies by the same geologist, in some of which I had the pleasure of participating, resulted in the discovery of other remnants which were inferred to represent a once continuous drift-sheet long antedating the moraine-fringed drift and grading into the Columbia formation. At the Rochester meeting, however, a different interpretation was placed on the phenomena, which were in part ascribed to local causes such as soil-cap movement, and in part described as that shadowy omnibus for the unknown, called the "fringe," and this despite the contention of skilled geologists familiar with the phenomena. Accordingly the substantial adoption of Professor Salisbury's main contention is especially gratifying. It is none the less gratifying that Professor Wright goes even further in his inter-

pretations than Professor Salisbury in seeking to lay down a definite boundary for this earlier drift.

The author does not, indeed, recognize, with Professor Salisbury and others, the full import of the evidence of diversity in age of the two drifts, but his excellent description of the phenomena clearly indicates the topographic distinction between the areas of older and newer drift, and show that the former must have been much longer subjected to erosion than the latter.

It seems to me that one of Professor Wright's inferences is open to grave question. He argues, from the local origin of the materials of the older drift, that the ice-sheet by which it was deposited was thin and feeble. Now, there seem to be good reasons for holding that a thin and feebly acting ice-sheet would not attack the local surface with sufficient energy to produce abundant local débris, and this view is in accord with the glacial phenomena of the Mississippi basin, where, in the region in which the ice-sheet is known to have been thin and of moderate activity, the drift is predominantly erratic, sometimes indeed containing very little local material.

These are questions, however, of minor importance; the highly gratifying fact remains that Professor Wright's conclusions are in substantial accord with the work of other geologists in the same region and in other parts of the United States.

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## Session of Tuesday Evening, August 15

The Society was called to order at 8 p m, in the Assembly Chamber of the Capitol, and a lecture illustrated by lantern views was delivered on—

### THE GRAVELS OF GLACIER BAY, ALASKA

BY HARRY FIELDING REID

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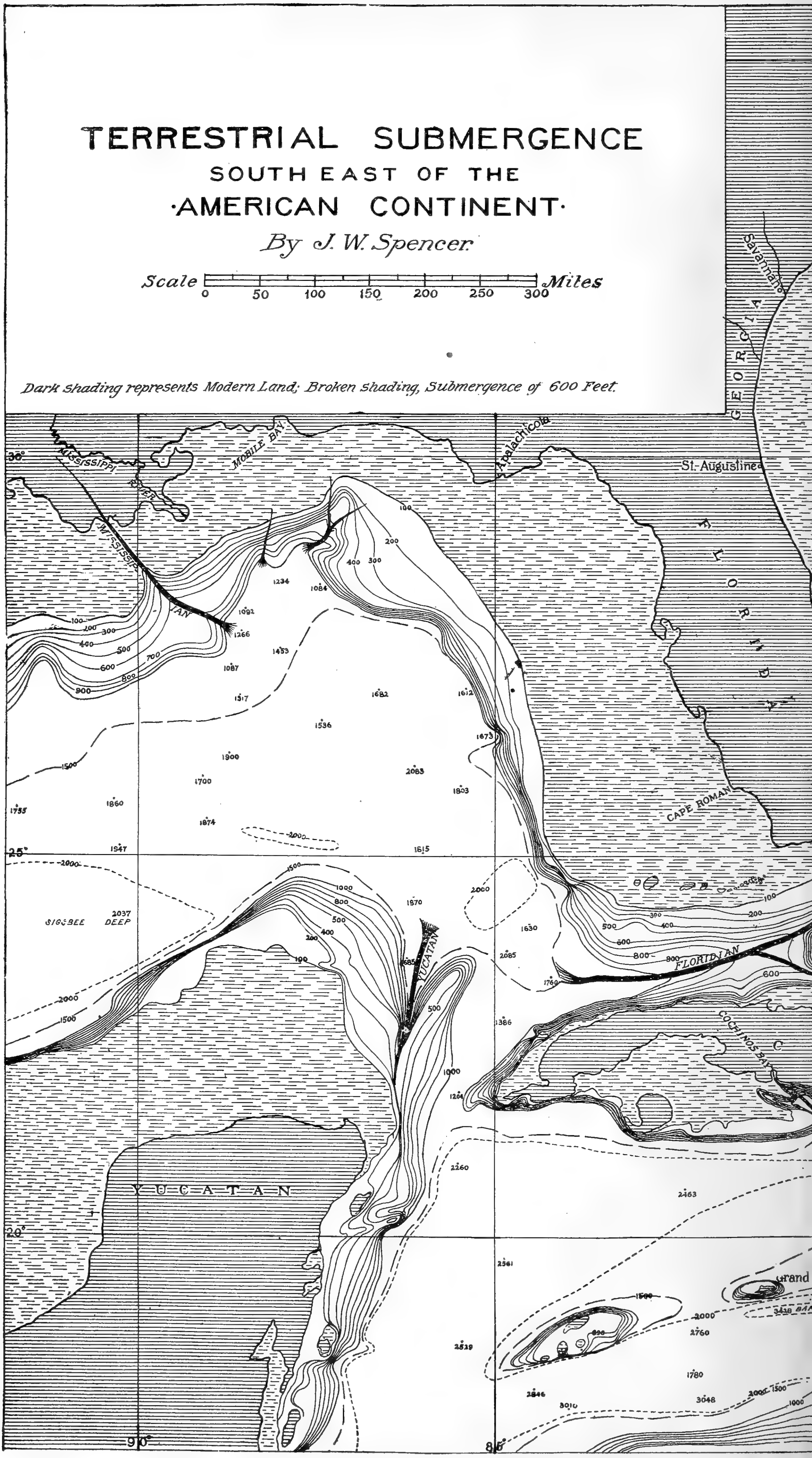
## Session of Wednesday Morning, August 16

Vice-President Chamberlin called the Society to order at 9 o'clock, and announced the titles of three papers which had been handed in since the printing of the program.

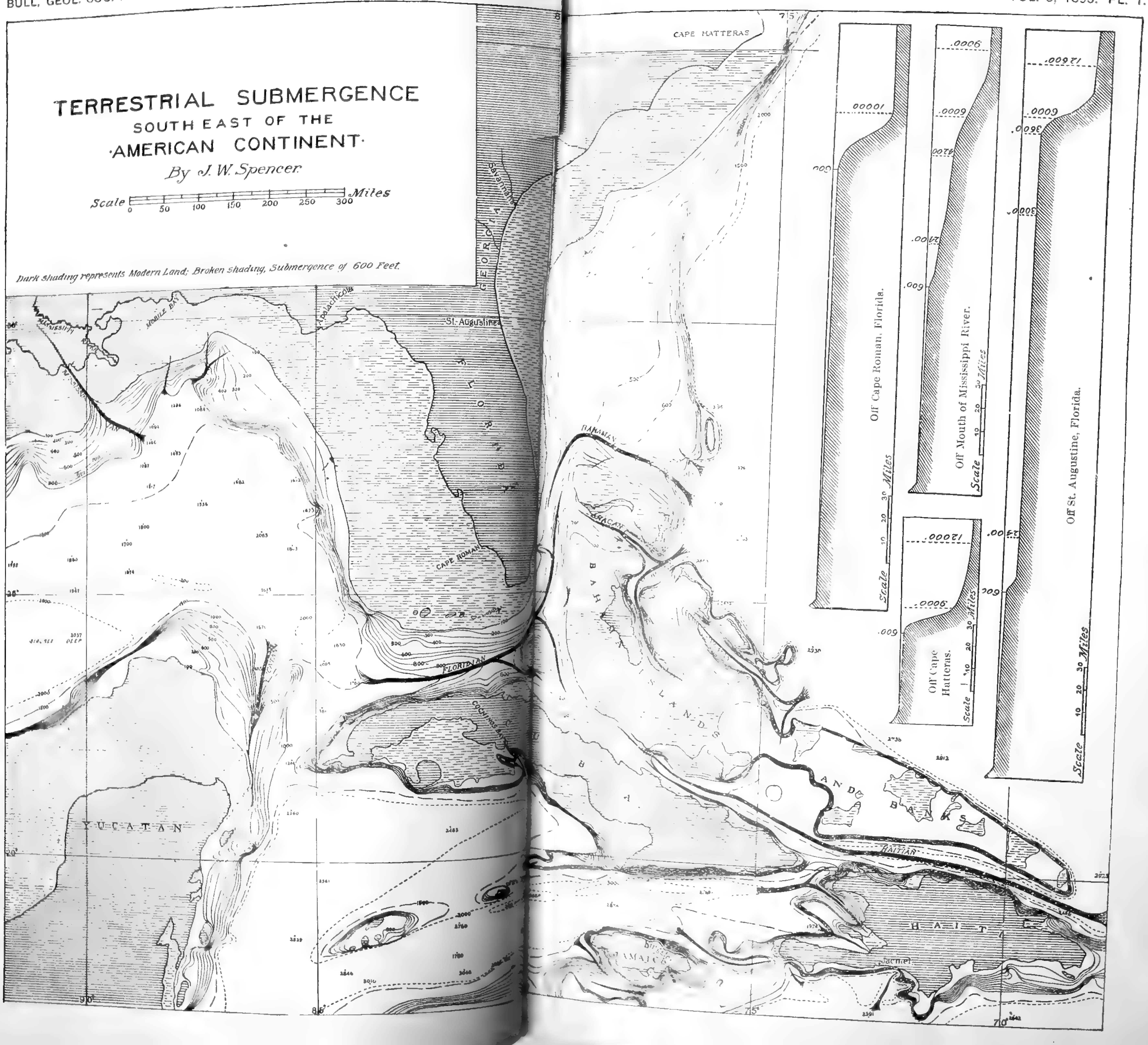
The Secretary read a communication from Mr G. K. Gilbert, giving reasons for a proposed change in the constitution which would permit the election of active Fellows outside of North America. The Secretary announced and commented upon other changes in the constitution and the by-laws which would be submitted, with the recommendation of the Council, to the Society for action at the winter meeting.

A letter was read from Professor G. H. Williams, inviting the Society to meet in Baltimore for its winter meeting of 1894.

The reading of scientific papers was declared in order; Vice-President Stevenson being called to the chair.


TERRESTRIAL SUBMERGENCE
SOUTH EAST OF THE
·AMERICAN CONTINENT·
By J. W. Spencer
Scale 0 50 100 150 200 250 300 Miles
Dark shading represents Modern Land; Broken shading, Submergence of 600 Feet.
GEORGIA
Savannah
St. Augustine
FLORIDA
MOBILE BAY
Apalachicola
MISSISSIPPI RIVER
CAPE ROMAN
FLORIDIAN
COCHINOS BAY
YUCATAN
SIGSBEE DEEP
30°
25°
20°
90°
85°


CAPE HATTERAS
75°
BAHAMAN
ANDROSAN
EXUMAN
HAITIAN
B A H A M A ISLANDS
AND BANKS
HAITI
JAMAICA
Kingston
Jacmel
70°
Off Cape Roman, Florida.
Off Mouth of Mississippi River.
Off St. Augustine, Florida.
Off Cape Hatteras.
Scale
Miles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BAHAMIAN
BAHAMA ISLANDS
COCHINOS BAY
YUCATAN
HAITIAN
HAITI
JAMAICA
Jacmel
Off Cape Roman, Florida.
Off Mouth of Mississippi River.
Off St. Augustine, Florida.
Off Cape Hatteras.
Scale 10 20 30 Miles

The first paper read was—

## TERRESTRIAL SUBMERGENCE SOUTHEAST OF THE AMERICAN CONTINENT

BY J. W. SPENCER

[*Abstract*]

Only an abstract of the paper is offered to the Society for publication, as the author proposes further investigations before writing on several questions closely related to the principal phenomena bearing upon the problem. This paper is a sequel to "High Continental Elevation preceding the Pleistocene Period," read before the Society August, 1889. At that time, epeirogenic movements of 3,000 feet seemed the limit of acceptability, although terrestrial elevation of probably short duration was shown to have reached from 4,500 to 6,000 feet along the continental margins, off the gulfs of Saint Lawrence and Maine and the mouth of the Mississippi river.

Recent studies of the valleys among the southern Appalachian mountains, of the adjacent Paleozoic table-lands, and of the Cretaceous and Tertiary plains of the southeastern states have convinced the author that the valleys, whether narrow or a score of miles or more in width, have been directly produced by atmospheric agents and by the erosion of a multiplicity of streams operating during the long periods necessary for the decomposition and removal of limestones. Some idea of the length of these periods is obtained when we find that from 100 to 200 feet of residual sandy clays have been left after the removal of the calcareous matter from the impure limestones. These southern valleys are independent of the mountain movements, in so far that they are not troughs of folds but anticlinal valleys. Even at the watersheds between streams flowing in opposite directions, the width and depth of the valleys are as often great as that between Lookout and Wills creeks or those along the Coosa and Tennessee rivers, where they are from 4 to 20 miles wide.

The valleys and channels among the greater Antilles and between them and the continent are an exact reproduction of the land valleys of the south. On a larger scale, the Laurentian valley, holding the Great Lakes, is another example, but this has been recently obstructed by the tilting of the earth's crust toward the north and east—the warping movement increasing from zero to two, four, six and probably even ten feet per mile. From the close analogy cited, the author concludes that both the land and the submerged Antillean valleys were of common subaërial origin.

Of the submerged valleys and channels there are two classes—those cutting across the continental shelf and others parallel to the mountain ridges. Of the former class, the fjord of the Mississippi river reaches to 4,500 feet in the upper platform and in the lower shelf to a depth of 8,000 feet. Cochinos bay, south of Cuba, is one of the most remarkable fjords, being 3,738 feet deep near the head of the bay and increasing in depth to 11,400 feet, with land on one side and shallow water on the other. The Yucatan fjord, entirely submerged, increases from a depth of 4,500 feet to 10,000 feet. The Bahaman fjord on the Atlantic margin of the continent is 12,000 feet deep. Scores of other examples can be cited, as in Jamaica, Haiti, adjacent to the Virgin islands, etc. (See accompanying map.)

Of the valleys parallel with the trend of the islands, there may be cited the Haitian channel, more than 500 miles long and reaching to a depth of 14,000 feet. Another example is seen in the channels between Haiti and Cuba, which descend

until, as in the case of Bartlett deep, south of Cuba, the extreme depth of over 20,000 feet is reached. All of these valleys are joined by numerous tributaries.

Such channels as the straits of Florida are only the junctions of valleys trending in opposite directions, even the common watershed of which is submerged. While the author regards all of these submerged valleys as originally terrestrial, yet he accedes to any hypothesis that may call for their enlargement by marine currents, which, however, do not appear to be scouring agents below the rims of the submerged basins; as, for example, the valley extensions of the Floridian straits, below the depth of water in its shallowest portions (about 2,000 feet), which have not been materially affected by the marine currents. This hypothesis is supported by temperature soundings.

The submergence indicated by the channels means great epeirogenic or extensive continental land-movements. The oldest formations of Cuba, Haiti, Trinidad, Barbados, etc, appear to be no older than the Cretaceous period. The oldest sediments are shales, sandstones and conglomerates (even at the base of the group in Santo Domingo) showing former continental connections, which would demand the enormous changes of level at an earlier period than that of which this paper treats. With this connection or the mountain-building of the early Tertiary, or even that after the Miocene period, the author is not concerned, but with those quieter extensive regional or epeirogenic movements which have slowly submerged great areas without obliterating the former land topography. The time of greatest land development was probably after the Pliocene period, if, according to McGee, we regard the Lafayette formation of that age. Into the discussion of the exact age, however, we cannot enter until further investigation. For the present, let us say that this great continental extension was since the later Tertiary times and was followed by movements in both directions, for modern deposits have been lifted to considerable elevations on the islands. This late continental elevation is not disproved by biologic evidence, but rather sustained. The drainage of this extensive land area was largely into the Pacific, or its embayments extending across portions of Central America and Mexico and indenting the western coast of the Antillean lands. The watershed between the Atlantic and Pacific drainage is still represented by the mountains of Cuba, Haiti and the Windward islands. They are situated near the Atlantic border of the continent, just as are the Appalachians of the southern states.

The closing of the western drainage involves recent tilting or regional uplifts forming the western rims of the Mexican and Caribbean basins. Similar movements have been demonstrated by the author in connection with the barriers of the Laurentian valley now producing the Great Lakes, which have been obstructed by the land rising along an axis transverse to that of the outlet of the old valley.

What has been the recent mean depression of the Antillean continental extension? From the depths of the fjords cutting through the continental plateau a subsidence of from 8,000 to 12,000 or possibly 14,000 feet is apparent; but probably this epeirogenic movement was not originally uniform, or, if so, it has been partly deformed by more recent movements, so that the author regards the 20,000-foot abyss (Bartlett deep), just south of Cuba, and even part of the Haitian channel north of that island, as partly due to a downward local warping of the deeper portions of the valleys. In the case of the Bartlett deep a basin has been produced. This great continental depression diminished to the north, so that the southern states have only been partly submerged. The present elevation of Central America represents complex movements.

A consideration of the continental elevation and its effect on the erosion of the valleys; the differential depression of the land which followed the elevation; the different epochs of variable movement; the biologic evidence noted, and other questions are portions of the study an advance notice of which is here recorded. To Messrs Jukes-Brown and Harrison, whose discoveries of oceanic deposits in Barbados were accepted by themselves and others as evidence of an upward movement of 2,000 fathoms and more, the author owes much encouragement in venturing, without precedence in this country, to bring before this Society evidence of epeirogenic movements (apart from orogenic) in very recent geologic times, amounting to two and a half miles of vertical subsidence of great land areas, thus proving the mobility of the earth's crust, although no explanation can be suggested at present to account for such stupendous movements.

Remarks upon this paper were made as follows:

W. P. Blake:

The extremely interesting paper of Mr. Spencer gives me an opportunity to mention some unpublished observations which are pertinent to the subject. In following the footsteps of Columbus in the island of Santo Domingo, I crossed the line of what appeared to be a remnant of an ancient marginal corralline limestone reef at an altitude of about 2,000 feet above the sea. There was no opportunity for extended examination, but it greatly resembled the corralline limestone terrace of post-Pliocene or modern age which borders this and some of the other West India islands at the sea-level or a little above it. The occurrence was so startling in its evidence of a recent elevation of the island as to cause me to refrain from accepting its full significance; but in the light of further evidence I am now inclined to accept it as proof of a modern uplift and, of course, a former depression, thus showing an oscillatory movement.

The marginal limestone, as is well known, is but little raised above the sea-level, and has long been exposed to aërial decomposition, by which it has become covered with a thick red soil.

W J McGee:

Both the author and the Society are to be congratulated on a paper of this character, dealing as it does with the outlying phenomena of our continent, by which alone its relations to other lands may be traced. It has long been recognized that the great system of islands lying off the Florida coast simulate the peaks and crests of a mountainous land, and it has been inferred by different geologists that the apparent condition is the real one, and that these islands are the monuments of a drowned continent. This inference is greatly strengthened by Doctor Spencer's recognition of rain-fashioned slopes and river-carved valleys in the deeps between the island-tipped mountains. Hitherto the profound crustal movement indicated by these phenomena has not been correlated with the lesser crustal movements of the North American mainland, and Doctor Spencer's provisional correlations are accordingly of exceptional interest and value.

While, as the author has shown, the general configuration of the island region suggests geologic youth, there appears to be some reasons for questioning whether the profounder movements were not considerably more remote. Inspection of the relief map giving submarine configuration shows that the Bahamas and neighboring islands are bordered by submarine terraces, or, perhaps more properly, flanked

by a broad, submerged plain surrounding them and their neighbors and merging with the submarine plain flanking the Atlantic and Gulf coasts of the mainland; and the plain circumscribing the islands is nearly as broad and continuous as that skirting the continent. Thus the submarine configuration would seem to connect and bind into unity the island-continent and the mainland. Now the age of the portion of this plain skirting the mainland is known, and it is significant that the plain does not represent a single episode or period, but has been in continuous process of accumulation since the beginning of the Cretaceous, if not the end of the Triassic; and it may accordingly be questioned whether the submarine shelf circumscribing the islands does not indicate equal antiquity, the somewhat greater width of the shelf along the American shore being counterbalanced by the greater width of tributary land area. This would carry the profound movement of the Bahaman region back to a period of profound movement in the mainland, indeed to the birthdate of our southeastern province and the drowning of the older land whence the Appalachian sediments came.

Warren Upham:

Concerning the time of erosion of the submarine valleys on our Atlantic coastal slope, it is especially noteworthy that they are cut in a descending plain of Tertiary and underlying Cretaceous beds; and the same condition is also known, by Mr J. Y. Buchanan's description, for the Congo valley or canyon cut in the submerged Tertiary border slope of the African continental plateau. In both regions the high epeirogenic uplift and accompanying stream erosion were evidently of late Tertiary and Quaternary age. If any long time had passed since the subsidence of the African continent, the muddy Congo waters must have filled both the very deep lower part of that river and the continuation of its valley offshore. Such great crustal oscillations in high latitudes, lifting the lands now overspread by the glacial drift, seem to me to have been probably the chief cause of the accumulation of their ice-sheets.

C. D. Walcott:

The sediments deposited in the Appalachian sea during earlier Paleozoic time were largely derived from an elevated land area to the eastward, and it is probable that this area furnished sediments throughout Paleozoic time and was several times eroded to base-level and in turn elevated to supply additional mechanical sediments to the Appalachian sea. The extent of this elevation is unknown, but it must have been considerable. When the final depression of the Atlantic coast area took place, it appears to have been largely on the line of the fault forming the "fall-line" between the Coastal plain and the Piedmont plateau region.

While it is evident that there has been a most extensive elevation of the southeastern portion of the continent, there is no proof that the continent as a whole has ever been correspondingly depressed beneath the ocean's water. Nowhere on the surface of the continent have deposits characteristic of the deep sea been discovered. On the contrary, all of the sedimentary rocks were deposited in interior or marginal seas within the limits of the continental plateau; also it is not in evidence that the relative position of the deep sea and the continental plateau has changed since Algonkian time.

Mr Spencer's contribution to the subject of the epeirogenic movements of the continent is a most interesting and valuable one, and I shall look forward with great interest to the publication of his memoir.

The following paper was then read :

EVIDENCES OF THE DERIVATION OF THE KAMES, ESKERS AND MORAINES OF THE NORTH AMERICAN ICE-SHEET CHIEFLY FROM ITS ENGLACIAL DRIFT

BY WARREN UPHAM

This paper is printed in succeeding pages of this volume, and the discussion by T. C. Chamberlin, Frank Leverett and H. F. Reid accompanies it.

The Acting President made some announcements and declared the meeting adjourned for the noon recess.

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## Session of Wednesday Afternoon, August 16

Vice-President Stevenson in the chair. Meeting called to order at 2 o'clock.

The Editor, Mr J. Stanley-Brown, stated that the undistributed brochures of volume 4 were printed and ready for mailing, except the proceedings of the Ottawa meeting which were in print and nearly ready for the members.

Upon motion of Professor I. C. Russell, it was voted that the special committee on the communication from the Alpine Club be increased by adding to the committee H. F. Reid and R. D. Salisbury.

It was moved by Professor I. C. Russell, and voted, that a committee of three be appointed to take into consideration the matter of making the Mount Ranier Pacific Forest Reserve a national reserve, and the committee was given power to memorialize Congress, or take other measures as they deemed advisable. The following Fellows were elected as such committee: David T. Day, S. F. Emmons and Bailey Willis.

The first paper of the afternoon session was entitled :

THE SUCCESSION OF PLEISTOCENE FORMATIONS IN THE MISSISSIPPI AND NELSON RIVER BASINS

BY WARREN UPHAM

This paper is printed in the succeeding pages of this volume, and the discussion by W J McGee, J. W. Spencer, R. D. Salisbury and T. C. Chamberlin accompanies it.

Vice-President Chamberlin assumed the chair, and the next paper was:

## CENOZOIC HISTORY OF EASTERN VIRGINIA AND MARYLAND

BY N. H. DARTON

This paper was not offered for publication. Remarks upon it were made by W J McGee, J. A. Holmes and R. D. Salisbury as follows:

Mr McGee:

Mr Darton's paper is an important contribution to knowledge of coastal plain geology. Despite the presumptive unity of the Columbia formation, certain diversities have been recognized since it was first discriminated, and in the original description two phases, designated respectively the "fluvial" phase and the "interfluvial" phase, were characterized. It has long been recognized, too, that the topographic configuration of the phases is dissimilar, the high-level or interfluvial phase displaying topographic adolescence or maturity, while the low-level or fluvial phase is so nearly free from subaërial structure as to stand for topographic youth. This diversity was tentatively and hypothetically explained as the result of unequal altitude above base-level; but, in view of the recent observations, the tentative explanation seems less probable than before. Perhaps the most significant of Mr Darton's conclusions is that relating to the inequality in coastal warping during the respective periods of depression which he has described. This may perhaps be regarded as the most nearly conclusive line of evidence of genetic bipartition of the Columbia formation.

Should Mr Darton's tentative division of the Columbia formation be supported by later work in other portions of the Coastal plain, especially in New Jersey, it will of course become necessary to modify the original nomenclature, perhaps by retaining the old name for one division and applying a new term to the other, possibly by abandoning the term Columbia and giving distinctive names to the different deposits. This is, however, a matter for the future; the application of the name Columbia served as a milestone marking progress in geologic research in the Coastal plain; but when the important vicissitudes in continental evolution for which it stood are generally recognized and come to be more clearly pictured, perhaps the occasion for preserving the monument will disappear.

Professor Salisbury:

I am interested to observe the twofold divisions of the Columbia formation, which Mr Darton has clearly brought out. I am glad to say, also, that north of Mr Darton's territory, in New Jersey, a twofold division of the Columbia seems to exist. These divisions will perhaps be found to correspond to his "high-level" and "low-level" phases. I think it may prove to be necessary to separate these two divisions of the Columbia, and to assign to one portion a new name, though we perhaps know too little of their genetic and chronologic relations to make this subdivision advisable at present. Evidence is accumulating in New Jersey which seems to point to the separation of the later from the earlier Columbia by a considerable time-interval, accompanied by considerable orographic movements. This statement is made on the supposition that the reference of beds to the Columbia has been correct. I am sure we have not made this formation include more than has been included in it further south.

The following paper was presented informally:

THE GEOLOGICAL EXHIBITS AT THE WORLD'S COLUMBIAN EXPOSITION

BY G. H. WILLIAMS

Vice-President Chamberlin announced the purpose and proposed program of the World's Congress of Geology to be held in Chicago August 21–26.

The following paper was then read:

## WISCONSIN LEAD AND ZINC DEPOSITS

BY WILLIAM P. BLAKE

*Contents*



### Introduction.

In a critical review of the progress of geologic work in Wisconsin, which I had the honor to present last winter to the Wisconsin Academy of Sciences, after giving in detail the views of Percival, Whitney and Chamberlin upon the existence of faults and dislocations of the strata, I stated my conviction that faults or dislocations do exist, and that they have a direct though perhaps obscure relation to the localization of the mineral deposits. It was then and is now my purpose to maintain that Percival's original observations and explanations of the cause of the well-known irregularities in the position of the strata were correct, and that the true path leading to the solution of the problem of the origin of the zinc and lead deposits of the Mississippi valley lies in the direction indicated by that gifted man rather than in the path marked out by later observers in the same field.

### Review of recent and former Investigations.

The subject, which has special interest to the region in which we meet, derives additional interest and importance at this time from the attention it is receiving from others. A memoir upon the subject has just been presented to the American Institute of Mining Engineers by Professor W. P. Jenney,* and was under discussion in one of the sessions of the Engineering Congress by Arthur Winslow, state

* The Lead and Zinc Deposits of the Mississippi Valley, by Walter P. Jenney: Trans. Am. Inst. Mining Engineers, August, 1893, p. 55.

geologist of Missouri, Professor Raymond and the writer. Professor Jenney finds that not only the Wisconsin zinc and lead-bearing strata, but also those of Joplin, Missouri, and its vicinity, are extensively faulted and broken, and that these faults and breaks following or related to the main axes of uplift have determined the position of the metalliferous deposits. He further claims that the metallic deposits are formed by ascending solutions, and that in their origin and formation they are no exception to the general phenomena of mineral veins. This may be said to be a complete reversion to the original view of Percival and to the then generally prevalent idea of the deep-seated plutonic origin of the ores of metals.

While in accord with Percival and with Jenney upon the existence of faults and dislocations in both Wisconsin and Missouri, I am not prepared to accept their views of the origin of the ores, my own observations confirming, in general, those of Whitney and of Chamberlin and his associates upon the last survey of Wisconsin, and inclining me to the theory of the original distribution of the sulphides of lead and of zinc in the substance of the limestone and dolomites at the time of their deposition and the subsequent concentration of these sulphides in the fissures of the rocks by lateral and downward flow of solutions of the metals rather than by the ascent of such solutions from lower strata.

An objection to Percival's views of a connection between the faults and the mineral deposits is found by Professor Chamberlin in the fact, so claimed, that the faults specifically mentioned by Percival are not contiguous to mineral deposits. If this is indeed so, it shows only that faulting is not necessarily in all cases accompanied by mineralization. It has yet to be shown that the mineralized areas are not upon or contiguous to lines of faulting or dislocation, and that they are so contiguous I shall endeavor to show in this paper.

Professor Chamberlin* thinks it not a little strange that, though Percival seems to have believed that the centers of elevation, which I understand to mean rather lines of disturbance and of break, were indices of agencies influential in the deposition of the ores, he should not have observed that none of them are centers of ore-deposits. He thinks Doctor Percival's observations do not show close connection or clear relation between elevations and ore-deposits, but rather the contrary.

Professor Chamberlin admits the existence of disturbed or flexed strata in the lead region. He calls them "local flexures," and refers them to unevenness in the original deposition of the strata, and does not find the deposits of ore to be coincident in place with the convexities of the beds and rocks, but does find the ore-deposits in the depressed areas. He asks "but if the deposits are not upon the swells of the strata are they in the sags?" † and answers this by citing an instance of such an occurrence at Dutch Hollow, where the mineral ranges lie within a trough or syncline the flanks of which have a dip of 15°. The rock in the axis is brecciated and the ores deposited in the brecciated mass form a true stockwork. Professor Chamberlin† cites this as a "marked instance of productiveness along an axis of depression, and of barrenness along that of elevation."

A notable arching of the beds is noted as lying south of the Potosi district, and the conclusion is stated that the Potosi diggings lie in a stratigraphic basin. The Trenton limestone seems to thin out and the Saint Peter's sandstone rises rapidly, and he finds the phenomena consonant with his view that the undulations had their beginnings in submarine inequalities, and he cites where ore-deposits appear to occupy synclinal depressions rather than anticlines, and he arrived at the con-

* Geology of Wisconsin, vol. iv, p. 429.

† Op. cit., p. 432.

clusion that "the ore-deposits usually, possibly not universally, occupy depressions in the strata." *

### Relation of Deformation to Deposition of Ore.

*Position of Accumulations of Ore.*—According to the generally accepted view of the accumulation of the ores by lateral secretion or leaching, it is not strange that the heavier deposits are found in the depressions where we should expect them to be, but it is not clear to me in the cases cited that the flexing of the beds, the synclines and anticlines, are due only to the original inequalities in the ocean floor and are not accompanied by any fracturing or displacements. Do we not have in the broken, brecciated beds evidence of disruption; and is it clear that in all cases these depressions are not monoclines ending in faults? We may also ask whether we do not find the simplest explanation of the inequalities of the strata to be that they have been subjected to uplifts and downthrows occurring in all the ages from early Silurian time onward? A line of break and movement once established at an early period would no doubt be perpetuated in succeeding formations, and would explain many of the observed phenomena of thinning out locally of some of the strata and their want of horizontal continuity.

*Examples of Faulting.*—A few examples which have fallen under my observation may here be cited.

In addition to two or more abrupt transitions visible horizontally in the levels of the Helena mine † from the horizon of the quarry-rock and oil-rock of the upper Trenton limestone to the lead and zinc-bearing beds of the Galena dolomites, we have a fine example of a dislocation, open to the surface, about a quarter of a mile west of the Helena mine, in the left bank of the Shullsburg creek, just east of the line of New Diggings township. At that point there is a fine exposure of the Trenton limestone—the "quarry-rock"—in a bluff rising abruptly from the water to a height of from 10 to 20 feet. The strata, which appear to dip westward, rise gently eastward as far as a little dell or ravine descending from the southward, where the limestones disappear from view. On the other side of this ravine about 100 feet away a tunnel driven in at the creek level passes into the coarse grained Galena dolomites and gives access to a long stretch of zinc and lead-bearing ground trending southeasterly, following crevices known to the miners as "10 o'clocks," being nearly at right angles with the general northeasterly trend of the main ore-bearing crevices of the Helena mine and parallel with two other known northwesterly crevices.

Beyond this tunnel to the east the Trenton limestone is again found. It would thus appear that a block of Galena dolomite has here dropped below the horizon of the Trenton on each side of it. The displacement is not very great, but it appears to be a veritable fault, or a compound fault, accompanied by heavy mineralization of the Galena dolomites. It occurs so abruptly and within such a limited distance as to preclude the idea of a flexure of the beds.

Examples of evident dislocation might be multiplied, but one instance such as here cited will, I think, suffice to establish the fact that disturbances of relative level do exist, ‡ and in direct connection with mineral deposits.

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* Op. cit., p. 438.

† One of the properties of the Wisconsin Lead and Zinc Company and situated three miles west of Shullsburg on Shullsburg creek.

‡ The recent paper, Some dynamic Phenomena shown by the Baraboo quartzite Ranges of central Wisconsin, by C. R. Van Hise: The Journal of Geology, vol. i, no. 4, 1893, p. 347, has a bearing upon the questions at issue.

*Localization of mineral Deposits by Faults.*—In explaining the localization of deposits by faults it is not necessary to suppose that the openings gave vent to mineral solutions. A simpler explanation suffices, and the phenomena are better explained upon the hypothesis that such linear breaks in the ocean-bed gave an outlet to fresh water in large volumes from such a source as the Potsdam sandstone, or to carbureted hydrogen gases or sulphureted hydrogen, either of which would destroy marine life and cause the accumulation of its remains in the sediments. Either sulphureted gases or carbureted hydrogen would act directly upon sea water and cause the precipitation of mineral sulphides, while the decomposing animal remains would continue this reduction and cause the accumulation of pyritic ores in the mass of the sediments in the vicinity of the faults.

The hypothesis of the precipitation of metallic sulphides from sea-water by the gases arising from decomposing animal and vegetable organisms was proposed by Professor Whitney, but he did not entertain the idea of the source of such or other precipitating gases in the faults, or of the possible destruction of organisms near the faulting planes. The accumulation of such organisms near the faulting planes would explain the localization of the mineral deposits if the precipitation of the ores was dependent upon animal and vegetable decomposition.

The phenomena of deposition of the sediments toward the close of the period of the Trenton blue limestone are significant of a sudden incursion of muddy water accompanied by petroleum. Although the upper layers of limestone are more thinly bedded than the lower, so much so that they readily break up into tabular masses and thin plates or flags, the rock retains its composition and dense homogeneous character. The remains of shells, however, become more numerous and the surfaces of the flags are marked by very thin, shaly partings and many protuberances, consisting largely of the remains of brachiopods.

## Relation of the Oil-rock to the Ore-deposits.

In the so-called "oil-rock" of the Shullsburg region we have ample direct evidence of the sudden formation of hydrocarbons, and it does not appear that the significance of this occurrence in connection with the mineral deposits has received the amount of attention it deserves in any attempt to explain the phenomena of the deposition of the lead and zinc ores. Professor Chamberlin has, however, indicated the possible functions of the carbonaceous layers of the Trenton limestone in causing the deposition of blende in the shale, and apparently after the formation of the shale, the disseminated grains of blende, known to the miners as "speckle jack," being found between the thin layers of the shale in such a way as to indicate this.*

This oil-rock is a true petroleum shale. A considerable quantity of thick petroleum can be distilled from it, even after it has been exposed to the weather for years. It does not occur in quantity, but is generally in very thin layers not much thicker than card-board or blotting-paper and film-like dividing layers of compact and highly fossiliferous limestone, but it sometimes attains a thickness of several inches and is in several layers separated by limestone full of fossils. The color is chocolate-brown, and is in strong contrast with the limestone, especially when wet, by which the color is much darkened. It appears to have been suddenly formed, the line between it and the limestone is sharp and distinct, and its posi-

*Geology of Wisconsin, vol. iv, p. 546. There are numerous examples of this in the Shullsburg region. Sometimes extensive workable beds are found, and the mass appears to have been formed together. The blende is often rosettes or crystalline nodules—"strawberry" or "blackberry jack."

tion in the midst of great masses of fossils indicates that a sudden incursion of hydrocarbons was the cause of the death of the organisms.

The petroleum shale appears to be calcareous rather than argillaceous. Digestion in acids causes much effervescence, and leaves a brown spongy mass, which burns freely when dry. The fossil shells entombed in the shale are generally well preserved and are sometimes silicified.

Analyses of this rock show, as would be expected, a wide difference in the amounts of earthy and of volatile constituents in different specimens.

In the mines of the Shullsburg region this "oil-rock" is regarded as marking the lowest horizon of workable deposits of blende. It appears to be the floor of the heaviest zinc deposits upon which the sulphides are spread out in sheets and masses as if the shale were both impervious to the solutions and at the same time favorable to the deposition of zinc ore in the more porous upper portions. It is easy to believe that this floor of petroleum shale has acted as a reducing agent upon zinc and iron solutions, while retaining them by its impervious nature. The so-called "brown rock" and the "green rock" are believed to be modified forms of this oily deposit, where it is more ferruginous and clay-like and attains a greater development. It marks distinctly the horizon of the top of the Trenton limestone proper, the "quarry-rock" underlying the Galena dolomite. It is thus at the base of the chief mineral-bearing strata, and though there are instances of layers of blende occurring below this petroleum shale, they are regarded as exceptional.

## Evidences of Deformation.

*Crevices.*—The rectilinear and geometric arrangement of the mineral-bearing crevices, their parallelism, right-angled intersections, and their great length as compared with their breadth, are certainly evidences of some general and comprehensive cause of the fracturing. We are reminded of the experimental demonstrations of Daubrée in the torsion, to the shattering point, of the sheets of plate-glass, and find in the homogeneous vitreous limestones of the Trenton, known as the "glass-rock," the bed-rock of the lead region," a material which very closely satisfies the conditions of those experiments.

In a region so cut up by vertical fracture planes it would be surprising if some of the blocks were not displaced; we, indeed, cannot conceive of the possibility of all the blocks retaining absolutely their original horizon plane, especially where a flexed structure with its attendant strains coëxisted.

"*Barren Bars.*"—Another evidence of dislocation may be found in the generally observed phenomena of walls of hard unmineralized rock, known to the miners as "barren bars," which bound mining operations on one side like straight walls. The formation on the one hand will be open, porous and mineral-bearing, often "picking-ground" of the miner, while on the other a different rock forms a hard, unyielding, dense, barren wall, which cannot be broken without powder. These bars are often narrow and separate contiguous mineral-bearing strata. Examination of such bars I am convinced will show vertical displacements by which strata of different horizons are brought into juxtaposition horizontally.

## Relation of the Driftless Area to the Ore-deposits.

In any attempt to explain the origin of the mineral deposits we must not omit reference to the fact that the lead and the zinc region is approximately that of no

glaciation, the deposits being confined to the driftless area. While the glaciers swept southward on either side, the lead region escaped and has since early geologic time been subject to atmospheric influences. As a result, there is a great accumulation of decomposed rock in place in an highly oxidized condition. That these products of decomposition have been leached by surface waters there can be no question, and we may regard a portion at least of the upper mineral deposits as derived from a considerable thickness of formerly overlying rocks, now concentrated in the residuum of their decay or redeposited in the crevices and cavities of lower strata. The formerly overlying shales of the Hudson river or Cincinnati period of which we now have remnants only in the mounds along the southern margin of the zinc and lead region, may have been, in part at least, the original depository of diffused sulphides of zinc and iron. Such sulphides by long exposure to oxidizing conditions by the percolation of atmospheric water before and during the glacial period would form soluble sulphates which by contact with the underlying limestones or dolomites would be reprecipitated as carbonates, or, possibly, if brought in contact with active deoxidizing conditions, as sulphides.

Conditions similar to these hypothetical conditions are found at ancient Laurium, where, according to M. Huet,* deposits of zinc ore penetrate limestone strata below overlying schists. Interesting cross-sections of these deposits are given by Huet and are cited by Daubrée.†

Professor A. H. Winchell has suggested ‡ that the sulphide ores of the Wisconsin lead region have been derived from formations formerly overlying the Trenton even as high in the series as the Cretaceous, which he believes once covered the lead region and have been swept away. He thinks that the ores were deposited from the ocean in the Cretaceous age and found their way downward through the strata to their present horizon.

The existence of the ores in the driftless area and their absence in the same rocks beyond is good evidence of their superficial rather than deep-seated origin; that they have accumulated from above downward rather than from below upward, and that these ores were diffused in the mass of the preëxisting rocks. If the ores had been formed by the upward flow of solutions depositing their metallic sulphides along the walls of the fissures and crevices we should expect to find the roots of the deposits, so to speak, in the glaciated strata.

### General Distribution of Zinc in Sea-water in Silurian Time.

It does not appear necessary to invoke the aid of favoring currents of sea-water specially charged with metallic solutions, or the derivation of such solutions from remote and more favored shores, to enable us to accept the idea of the derivation of the zinc and lead ores from the ocean.

The fact that the older limestones and dolomites of both America and Europe, and probably, we may say, of the world, appear to be the special repositories of zinc and lead is evidence of a world-wide and not local distribution of the salts of zinc and of lead at that time. We find a series of remarkable workable deposits of zinc ore in the Appalachians stretching at intervals from northern New Jersey into Pennsylvania, Virginia and Tennessee. These deposits are either in the lime-

* Huet: Mémoire de la Société des ingénieurs civils, 1878–1886.

† Daubrée: Les Eaux Souterraines, vol. iii, pp. 104–106.

‡ Iron Ores of Minnesota, p. 153.

stones of the Trenton period or in close association with them. To the zinc and lead regions of Wisconsin and Missouri we may add those of Arkansas and of New Mexico, these last, at least, being in Silurian limestones.

The zinc ores of Tennessee are found for the most part in the lower beds of Trenton limestone or just below them in the magnesian limestones. The zinc ores of Claiborne, Tennessee, occur at intervals for 12 or 15 miles along a great anticlinal fold of the limestones.* The zinc deposits of Bald hill, on Powell river, Tennessee, are in a dark-colored fetid limestone† of Lower Silurian or upper Cambrian age.

In Europe, according to Burat, the ores of zinc used at the celebrated zinc smelting works of Belgium are obtained chiefly from dolomitic Silurian limestones, but Daubrée in his résumé of the discussion of the action of mineralized waters in the formation of masses of zinc ore indicates a much more general vertical range, for he says, in substance, notwithstanding local differences the deposits of calamine present striking analogies altogether independent of the age of the beds in which they are spread, whether Cretaceous, as in Spain; Triassic in Upper Silesia, the Duchy of Baden and central France; Carboniferous in Belgium and England; Devonian in some parts of Belgium, Prussia and Westphalia, or in Silurian, as in Sardinia.

In the western portion of the United States some of the more remarkable large bodies of zinc and lead ores, generally argentiferous, are either in or are closely associated with the older limestones. This, it is thought, is good evidence in favor of the contemporaneous origin of the sulphides of the metals with the mass of the rocks in which we now find them, and consequently that they, like the sediments, were derived from sea-water or were at least distributed by sea-water, the chemical conditions then favoring the precipitation more than before or since.

## Conclusions.

The chief points to which I desire to direct especial attention by this paper are:

1. That faults and dislocations exist in the Wisconsin lead and zinc region, and that these faults have a direct, though obscure, relation to the localization of the mineral deposits, as claimed by Percival.

2. That although it is not probable that the faulting planes gave vent to mineral solutions from below, they probably permitted the outflow of fresh water or of gases which acted upon the sea-water as precipitants of the metals and also as destroyers of the animal and vegetable life in their vicinity, by the decomposition of which organisms the accumulation of metallic sulphides in the rocks was promoted and to some extent localized.

3. That the significance of the thin oil-bearing shales at the top of the compact limestones of the Trenton period and at the base of the Galena dolomites has not been sufficiently recognized. These shales are rich in petroleum, and give evidence of sudden formation and of the attendant destruction of organic life. This "oil-rock" is at the base of most of the zinc deposits, and appears to have acted both as a retentive substratum, or floor of deposition, of blende and as a source of deoxidizing and of sulphurizing gases which have determined the reprecipitation of the zinc from sulphate solutions derived from the oxidation of the blende deposits above the water-level.

4. That the arrangement of the crevices indicates a shattering of the strata,

* Safford: Geological Reconnoissance of Tennessee, 1855, p. 74.

† Mining Magazine and Journal of Geology, second series, vol. i, p. 420.

especially those of the compact vitreous limestones of the lower Trenton, called "glass-rock," analogous to the fissuring obtained by Daubrée in shattering plate-glass.

5. That the coincidence in extent of the lead and zinc region with the "driftless area," as shown by Professors Chamberlin and Salisbury, and the absence of the ores in the glaciated areas tends to show that the ores have been derived from the mass of the rocks by gradual oxidation, secretion and lateral flow into the fissures during the geologic ages to which the rocks were exposed to atmospheric agencies.

6. That the chemical conditions favoring the deposit of zinc ores and of lead ores appear to have been world-wide and most favorable when the ancient Carboniferous and Silurian limestones were laid down.

## Discussion.

J. F. Kemp:

Although not personally familiar with the region described, I have seen much of similar deposits in southeastern Missouri and have been in close touch with Dr W. P. Jenney in his work on those in Wisconsin. A fault-fissure seems the most reasonable source of supply for such large bodies of ore, but it is extremely difficult to detect such as Professor Blake shows. Dr Jenney states that he has found evidence of horizontal faulting, but this is an obscure phenomenon to identify. At Mine la Motte, Missouri, experience has shown vertical faults, in one case quite extended, but near them the ore-bodies fade out into barren rock—the reverse of what we would expect were the fault-fissures a source of supply. Recent drilling has given some reason for believing that the ore favors, in a broad way, the places where low rolls or anticlines cross the faults. If the anticlines had once been more marked and a source of some shattering, had then been impregnated with ore and afterward subsided, a very puzzling ore-body would have resulted, with no very apparent cause for the original cavities, but with strong analogies with what we meet there today. The absence, however, of notable faults in Wisconsin adds much to the difficulties of explanation.

T. C. Chamberlin:

There is undoubted evidence of some disturbance of the beds which embrace the lead and zinc deposits, and, in some instances, the beds on opposite sides of a lobe lie at different altitudes, but I have never seen evidence which positively determined whether this was due to faulting or flexure. In the case of flats and pitchers, which constitute the notable feature of the lead-bearing deposits, there is evidence that the mass of rock embraced within the flats and pitchers has settled down somewhat, but this has never seemed to me to be an instance of faulting in the larger sense. While beds have been bent and crushed, and while there have been minor slips and settlings of the beds, I am not aware that there is any proof of general faulting which affected the great series of Paleozoic beds down to the crystalline rocks. It was faulting of this kind that was chiefly in my mind in discussing the subject of the ore deposits in the Wisconsin reports and not those slight minor dislocations which were of merely local and trivial extent. These latter disturbances were doubtless influential factors in determining the final localization of the ore deposits, but they could have no bearing upon the original introduction of the metalliferous material unless they extended through the strata below.

The next paper was entitled:

## GEOLOGY OF THE SAND-HILL COUNTRY OF THE CAROLINAS

BY J. A. HOLMES

[*Abstract*]

The coastal plain region of the south Atlantic and Gulf states is covered almost everywhere with a thin mantle of loose material, mostly loam, clay or sand, the latter predominating, and the general surface is either nearly level or gently undulating. Near the inland border of the region the topographic features and the sand-covering are more pronounced. In the Carolinas the sand-covered ridges and hills reach an elevation of 400 to 600 feet, while the brooks at their bases, within half a mile of the summits, run at a level of 100 feet, more or less, below, and the larger streams which separate the ridges and divides are but little above tide-level. Hill and valley alike are covered with a mantle of sand, which varies in thickness from 1 to 20 or 30 feet. This pronounced topography and sand-covering have given rise to a somewhat general use of the expressions "sand-hill country" and 'among the sand-hills." These expressions are sometimes applied locally to sections of the coastal plain region near the sea, where the wind-action has produced dunes, but such usage is local.

That part of this region which lies between the Neuse and Savannah rivers has been examined more particularly, and in this region the following sections will indicate fairly well the geologic structure:

*a.* A series of cross-bedded, medium to coarse arkose sands lying on the irregularly eroded surface of the crystalline rocks. These beds, which are classed provisionally as Cretaceous, contain in the upper layers in places lenses of clay and occasional thin beds and seams of lignitic material. They have been deeply eroded, their present surface rising nearly to the tops of the highest hills and sinking to the level of the deeper valleys.

*b.* Overlying these arkose sands near the tops of a few of the higher hills are to be found small patches of older Eocene deposits, remnants of a once extensive formation.

*c.* Overlying with marked unconformity the deeply eroded Cretaceous surface and the Eocene remnants are the loams and ferruginous sands of the Lafayette formation, which in turn have been deeply eroded and entirely removed over considerable areas in the drainage basins of the larger streams.

*d.* Spread out over this deeply and irregularly eroded surface, resting in places on the Lafayette or the Eocene or on the Cretaceous, or where all of these have been removed, even on the crystalline rocks, lies the mantle of sand and loam which is classed as Columbia.

Among the features in this region deserving special consideration may be mentioned the following:

1. The arkose sands, here classed as Cretaceous, which have a thickness in this region of several hundred feet, and near the coast a thickness of possibly more than 1,000 feet, indicate the removal of a large amount of material from the adjacent Piedmont plateau during Cretaceous time while this plateau was being reduced to base-level. The origin of the extensive beds of typical arkose material has not yet been satisfactorily explained.

2. Evidence of extensive erosion in this region during the interval between the Cretaceous and Eocene deposition has not yet been found to be conclusive, but in the coastal plain region further seaward such evidence does exist.

3. If extensive Miocene beds ever existed in this region they were removed before the time of the Lafayette deposition.

4. There are unmistakable evidences of two periods of extensive erosion: (*a*) One post-Eocene and possibly post-Miocene, but pre-Lafayette; (*b*) the other post-Lafayette but pre-Columbia. During the first of these practically all of the Miocene formation (if it ever existed in this region), nearly all of the Eocene, and a large part of the Cretaceous formation was removed from the Sand-hill country. During the second of these erosion intervals there was removed fully one-half of the Lafayette formation and additional portions of the formations underlying. There are evidences of limited post-Columbia erosion, but the amount is insignificant as compared with the work of the two erosion intervals just mentioned.

5. The extent of the submergence of this region during these succeeding periods of deposition can be made out approximately. Between the Cape Fear and Peedee rivers the position of the land during the later Cretaceous deposition could not have been less than 600 feet, and was probably not greater than 800 feet. The Eocene remnants capping the hills at an elevation of 500 feet above tide represent older Eocene deposits. The submergence during Eocene deposition could hardly have been less than 600 or 700 feet and may have been several hundred feet more, and the Eocene waters for a short time may have covered a considerable part of the Piedmont plateau and washed against the slopes of King's and Anderson's and the Sauratown mountains. Six or seven hundred feet may be stated as a probable maximum submergence during the deposition periods of the Lafayette and Columbia.

6. Observations have been made which will aid in determining approximately the amount of elevation of the land during the several erosion intervals, but they are not complete enough to warrant their discussion within the limits of this paper.

7. In conclusion, it may be stated that the general topography of the Sand-hill country is as old as the post-Cretaceous and post-Eocene erosion intervals. The valleys and stream channels formed at that time were subsequently filled or nearly so during the Lafayette deposition, but they were opened up again along the same general lines during the post-Lafayette erosion interval. This was followed in turn by the comparatively brief Columbia submergence, during which was laid down the thin covering of sand in the region under consideration, and of finer sand and loam and clay further seaward. These materials again filled the stream-channels and adjacent low, level valleys, and they are again being removed by post-Columbia erosion; but these recent changes have left the general topography much the same as it was long before.

In discussing the paper W J McGee said:

To one who is familiar with the difficulties attending field-work in the Coastal plain, the results of Professor Holmes' studies seem especially important. His contributions to the structural geology and the genetic history of this region have been so clearly stated as to leave no room for criticism and little room for remarks save in commendation. I beg, however, to direct special attention to the clearness and fullness with which he has elaborated that part of the region which was previously most obscure, *i. e.*, the later portion, represented by the vaguely defined

superficial deposits of sand and loam. His extended observations and cautious inferences have illuminated a dark chapter in the geology of the Carolinas.

The following papers were read by title:

### THE ARKANSAS COAL MEASURES IN THEIR RELATION TO THE PACIFIC CARBONIFEROUS PROVINCE

BY JAMES PERRIN SMITH

### GLACIATION OF THE WHITE MOUNTAINS, NEW HAMPSHIRE

BY C. H. HITCHCOCK

A recent visit to the White mountains has enabled me to complete the examinations needed to affirm that glaciation has been complete over the Presidential range of summits and cols. My earlier publications have related chiefly to Mount Washington, the highest of all the summits; for if the highest point has been glaciated it is presumable that the lower portions have been affected in a similar manner. Commencing at Mount Madison, the extreme northern elevation, and proceeding west of south and south to Mount Webster, the range may be specified as follows: Mount Madison, 5,380 feet; * lowest point in the divide or col between Madison and Adams, 4,912 feet; Mount Adams, 5,805 feet; col, 4,940 feet; Mount Jefferson, 5,725 feet; col, 4,980 feet; Mount Clay, 5,640 feet; Mount Washington, 6,290 feet; Lakes of the Clouds, 5,060 feet; Mount Monroe, 5,390 feet; Mount Franklin, 4,904 feet; col between Mount Franklin and Mount Pleasant, 4,400 feet; Mount Pleasant, 4,764 feet; Mount Clinton, 4,320 feet; Mount Jackson, 4,100 feet; Mount Webster, 4,000 feet; White Mountain Notch, 1,914 feet.

Above 5,000 feet the rocks have never been protected by vegetation, and consequently a more intense and longer continued freezing action has prevailed; hence ledges that were once as firm as possible after the removal of the shattered and decayed pieces have now been split into fragments. The glacialist everywhere else finds little or no evidence of postglacial dismemberment of the ledges through freezing, and has therefore been led to doubt the evidences that have been presented of the removal of the glaciated surfaces themselves.

The rock of the range is an easily splitting feldspathic mica-schist traversed by occasional veins and bunches of white and rose quartz. No signs of striation are visible upon the schists, though embossment of the ledges is frequently admirably displayed. Two excellent examples of glaciated quartz occur in the cols on both sides of Mount Adams, each about 5,000 feet high. In the most northern col the surface of the white glaciated quartz is 10 by 25 feet and the direction of the striæ S. 33° E.† More than half of the surface shows the striation; over the rest the lines have been obliterated, but the smoothing remains. By carefully examining these two kinds of surface one is enabled to judge whether the smoothed loose pieces of quartz found higher up indicate glaciation. Specimens of both these smoothed surfaces have been compared and it is impossible to distinguish them

* The heights are given above mean tide-water.

† The courses of striæ have been corrected for variation of the compass.

from each other; hence the conclusion is drawn that the smoothing upon many fragments of white quartz upon the higher summits is due to glaciation. The other quartz-ledge showing glaciation is in the Adams-Jefferson col and is 25 by 30 feet square, and is completely covered by delicate striæ running S. 55° E. One could not readily refer to a larger and handsomer area of glaciated white quartz at any lower level away from the mountains.

Every one of the cols in the Presidential range shows excellent examples of *roches moutonnées* and usually striæ and transported bowlders. The embossment in the cols adjacent to Mount Adams and Mount Pleasant are uncommonly fine. Those about the Lakes of the Clouds have been figured as good illustrations of ice action in my father's reports and text-book. No geologist familiar with ice-work can hesitate to recognize their glacial origin.

Mount Madison presents near the top the appearance of smoothing and obscure glacial marking, and a single pebble of green schist like that found in ledges in the town of Stark has been brought to me.

Mount Adams has changed its surface character somewhat since my first visit there twenty-two years ago. It was said then that "fragments are strewn universally over the cone. You can find one comparatively small block standing above every other one at the very apex." I now find that the loose fragments at the apex have been pushed downhill by tourists and engineers, so small is the summit; consequently glaciation is not visible; but a few feet lower down, on the north side, I found a rounded bowlder of granite of the size of one's fist comparable with the rock in Stark, and on two sides of the mountain, at levels from 100 to 300 feet below the apex, I found several blocks of hornblende and green schistose rocks such as are common about Groveton and Lancaster. Three-fourths of the way from the top of Mount Adams to the west base of the cone I found a protogene bowlder weighing 25 pounds. My notes also mention an apparently embossed ledge of rock quite near the summit of Adams, on the west side. Mr W. G. Nowell observed on the west side striæ at the altitude of 5,500 feet, and also on Mount Sam. Adams, 5,583 feet, with the direction S. 58° E.

Mount Jefferson is abundantly covered by transported stones, chiefly of protogene gneiss. On both the north and south flanks they are very noticeable and may be counted by the hundred. At the apex I saw one weighing 20 pounds. Two hundred and fifty feet below the summit, on the southwest side, I found near each other obscurely embossed ledges, smoothed fragments of quartz, apparently glaciated when in the ledges, and three bowlders, each estimated to weigh two tons. On the summit of Mount Clay there are obscure embossed ledges, and I picked up a small pebble of slate such as is common in Essex county, Vermont.

I wil simply say that on Mount Washington I have found many bowlders of protogene and other foreign stones on its northwestern slope and apex. The best example is a rounded bowlder of protogene weighing 91 pounds, found about 15 feet from the southeast angle of the Tiptop house, and presented to the Boston Society of Natural History. A supposed scoring measured S. 43° E. on a rock platform near the Signal Service station. Professor W. O. Crosby has verified the observations of transported bowlders on the summit of Mount Washington. At the Lakes of the Clouds the striæ point S. 22° E. and S. 52° E. Two hundred feet above these lakes the course is S. 30° E. In the Mount Pleasant cols the course is S. 30° E.; on Mount Clinton from S. 47° to 52° E.; on the south peak of Clinton S. 50° E.; on the top of Mount Webster S. 30° E., and farther south on a surface

40 by 200 feet S. 30° E. The bowlders seen southwest from the lakes are too numerous to mention.

Concerning the phenomena it may be remarked in general that—

1. The direction of movement, like that common in the vicinity, is southeasterly, and the materials have been transported uphill.

2. The bowlders have come from positions corresponding to the places of their dispersal. The protogene on Mount Washington and Mount Jefferson is thought to have been derived from Israel river valley, while the Huronian schists and granites on Mount Adams have come from Groveton and Stark, a region farther north. The protogenes have been transported more than 10 miles and elevated 4,000 feet; the Huronian schists 12 to 18 miles or more, and the slates probably 30 miles. No account is taken of the transportation of the bowlders of mica-schist, which may have been several miles.

3. The location of two or three lines of terminal moraines in northern New England is such as lead us to believe that their positions are not greatly changed by the presence of the higher peaks.

4. These remarks do not apply to the moraines of certain later local glaciers.

5. The arrangement of the recently discovered fragments is worthy of notice. In the first place, there are conical hills upon Mount Adams, say 50 feet high and 75 feet broad, consisting of the débris which has naturally fallen from a ledge. These correspond with the eminences in non-glaciated regions where the rocks have decayed and have been buried in their own ruins. From one point of view all the Presidential mountains are reverting to this condition. Secondly, I pointed out* in 1880 the fact that the angular stones are sliding down the mountain sides so as to resemble local moraines. They form sloping terraces, whose tops are grassed over and the escarpments consist of loose blocks which have not all reached their final state of equilibrium. I fancied, also, there was a tendency in the blocks to radiate from the outer edges of the terraces. They are really a species of flood-plain accumulation. I observed one block of stone about 9 feet long and 3 wide, which had been split from a larger piece, upon ground slightly sloping and had been moved about a rod. It had crept down the slope, probably when it was icy underneath. Its motion was undeniable, as its matrix was visible; so it would appear probable that all the stones in these terraces have been slowly creeping downhill, but falling considerable distances when the slope was steep enough. These terraces are sufficiently extensive and abundant to find a place upon surface-geology maps of a large scale.

Finally, glaciation has been complete all over the White mountains. We are compelled to explain why the ice has climbed from the low level of the Saint Lawrence and has overridden the high Montalban watershed. The motion of the glacial ice was so irresistible that this elevated ridge has not prevented its onward march. We can also satisfy ourselves as to the minimum thickness of the ice-sheet and the slope of the surface from the point over Mount Washington to the sea-level. The object of this paper, however, is not to discuss these and related questions, but simply to show that the evidence of glaciation over the highest of the White mountains has been satisfactorily substantiated.

The scientific program was declared closed.

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*Among the Clouds, August 7, 1880.

Professor R. D. Salisbury moved the appointment of a committee of three to send greeting in the name of the Society to Professor B. K. Emerson, who was unable to attend on account of injury in a railroad accident. The motion was voted, and the Chair named as such committee R. D. Salisbury, G Frederick Wright and H. S. Williams.

The following resolutions were presented by W J McGee and unanimously voted:

*Resolved,* That the cordial thanks of the Society be extended to the University of Wisconsin for the use of rooms and for various facilities enjoyed during the present meeting; and

*Resolved,* That the Society express hearty appreciation of the earnest and eminently efficient efforts of the Local Committee to render this meeting agreeable and successful.

Acting President Chamberlin made a few appropriate remarks and declared the Fifth Summer Meeting adjourned.

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## Register of the Madison Meeting, 1893

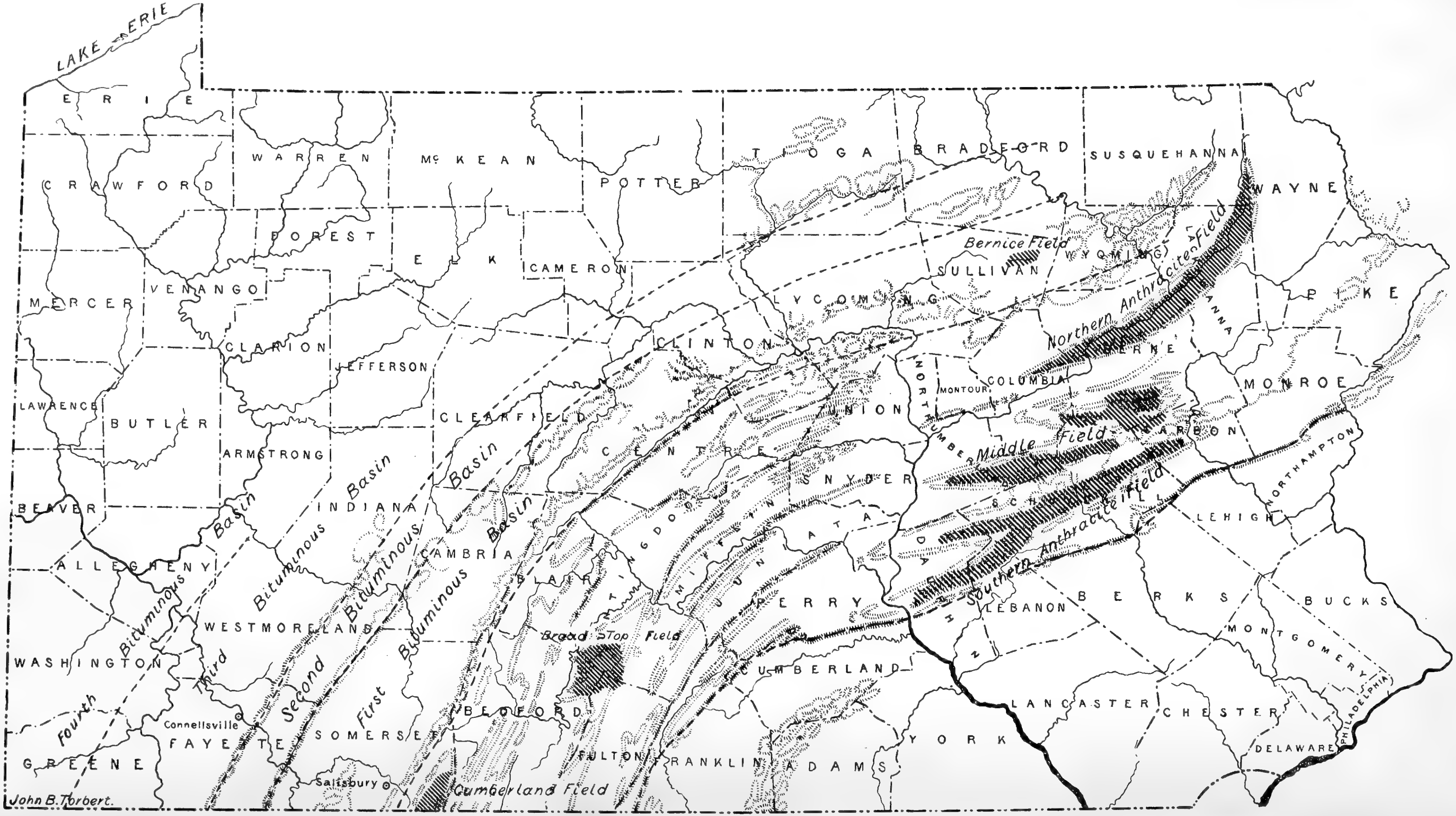
The following Fellows were in attendance at the meeting:

Robert Bell.
William P. Blake.
Samuel Calvin.
T. C. Chamberlin.
E. W. Claypole.
N. H. Darton.
H. L. Fairchild.
A. C. Gill.
Ulysses S. Grant.
L. S. Griswold.
Wm. F. E. Gurley.
Wm. H. Hobbs.
J. A. Holmes.
James F. Kemp.
C. R. Keyes.
Joseph Le Conte.
Frank Leverett.
W J McGee.
V. F. Marsters.
H. B. Nason.
Harry Fielding Reid.
Israel C. Russell.
Rollin D. Salisbury.
Fred. W. Sardeson.
J. W. Spencer.
J. Stanley-Brown.
John J. Stevenson.
A. S. Tiffany.
E. O. Ulrich.
Warren Upham.
C. R. Van Hise.
Charles D. Walcott.
Henry S. Williams.
N. H. Winchell.
Arthur Winslow.
G. Frederick Wright.

*FELLOWS-ELECT.*

C. H. Gordon. Albert A. Wright.

Total attendance, 38.




MAP OF PENNSYLVANIA SHOWING APPROXIMATE BOUNDARIES OF THE ANTHRACITE STRIP AND THE FIRST THREE BITUMINOUS BASINS.

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# ORIGIN OF THE PENNSYLVANIA ANTHRACITE

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*(Read before the Society August 15, 1893)*

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## Introduction.

Tables of analyses of coals from the Pennsylvania bituminous areas show that the proportion of volatile combustible matter decreases toward the east, though the rate of decrease is not regular and differs in the different beds. The decrease is even more marked in that portion of the state lying eastward from the bituminous areas, for there one finds the passage from semi-bituminous to the hard dry anthracite of the Middle fields.

## Pennsylvania Coal Areas.

### *General Extent.*

A general knowledge of the features and relations of the several coal fields or geologic basins in Pennsylvania, as well as of their extensions toward the south, is absolutely essential to an intelligent discussion of the cause of the decrease in volatile. The portions of these basins or areas lying within Pennsylvania was described by Professor H. D. Rogers in his final report on the geology of the state, to which the reader is referred

for details beyond those given here. It should be remembered in this connection that while the general trend of the Appalachian chain is from north-northeast to south-southwest, yet the system describes many curves, so that in some portions of its course the trend is almost east and west, a fact exceedingly important in its bearing upon the value of comparisons made along certain lines.

Immediately beyond the South mountain or Blue ridge is the Great valley which, with many names, extends almost unbroken from New England to Alabama and is bounded on its northwesterly side by a monoclinal ridge known in Pennsylvania as Kittatinny or North mountain, but by many names in its course through Virginia.

### *GEOLOGIC STRUCTURE.*

The first coal-bearing area is the somewhat complex region lying between the Kittatinny and the Alleghany mountain, the latter an irregular ridge traceable from Luzerne county southward almost to the Maryland line, where it becomes an anticlinal with the Cumberland or Potomac coal field at its easterly foot. In a general way, disturbance was much greater within the valley than within this second area, for Cambrian and Silurian rocks prevail in the former, whereas those rocks are deeply buried in much of the latter. In its northward extent, the latter is, comparatively speaking, a broad, gently folded area, in which rocks older than the Devonian are rarely shown and the Coal Measures have been preserved in deep synclinals known as the anthracite fields. Southward the plication is greater; new and abrupt folds make their appearance, so that in the central and other counties of Pennsylvania almost to the Maryland line, the Lower Silurian is present in broad spaces and Upper Silurian is a striking feature of the scenery. Still further southward, faults, for the most part insignificant in this portion of Pennsylvania, become more and more numerous until in southwest Virginia they are the characteristic structural features.

### *ANTHRACITE STRIP.*

As the result of this increasing plication southward, the Southern and possibly the Middle anthracite fields have no representatives in the southern counties of Pennsylvania, but the synclinal of Licking mountain, in Fulton county, just fails to hold the Coal Measures; it is where the representative of the Southern field should be. The Northern or Wyoming-Wilkesbarre field is represented in Huntingdon, Fulton and Bedford counties by the Broad Top coal-field. while still further southwestward and almost 20 miles nearer the Alleghany mountain is the

Savage mountain synclinal, holding the Cumberland coal field of Maryland and Virginia. These two fields are in such relation geographically to the Alleghany mountain on the one side and to the North or Kittatinny mountain on the other, that either one of them may be taken as practically representative of the Northern anthracite field.

*BITUMINOUS BASINS.*

Beyond the Alleghany mountain one comes to the bituminous coal basins, which are sharply defined in the southern portion of Pennsylvania, but become less and less defined northward, and soon disappear southward.

The first basin beyond the Alleghany mountain has the bold axis of Laurel hill as its western boundary in West Virginia and southern Pennsylvania, embracing Somerset and Cambria counties in the best defined portion. Northward the trough, ascending, becomes shallower, but it can be traced without difficulty to the New York line, holding small patches of coal in Lycoming, Sullivan and Wyoming, the latter two being in what is termed the Loyalsock coal-field. It forms part of the Mahoopeny mountain in the Loyalsock area, and is part of the Alleghany mountain in Lycoming, Centre and Clinton counties.

The second basin is well known in southern Pennsylvania as the Ligonier valley, bounded for more than 100 miles in Pennsylvania by the anticlinals forming Laurel and Chestnut hills or mountains. At the south it becomes well defined first at not far beyond the Baltimore and Ohio railroad in West Virginia, and embraces parts of Harrison, Taylor and Preston counties. It enters Pennsylvania in eastern Fayette, and continues through Fayette, Westmoreland, Indiana, Clearfield, Lycoming and Bradford counties, its last areas of coal being the Ralston in Lycoming and the Barclay in Bradford. Its coal-field ceases to be continuous beyond the Susquehanna river, which crosses it at Karthaus.

The third basin is a broad area, consisting, along the Pennsylvania railroad, of three sub-basins, which are well defined in Westmoreland county; but the basin practically becomes one at a short distance south from the Pennsylvania line in West Virginia. It embraces, in Pennsylvania, the Coke basin of Connellsville, the Greensburg basin of Westmoreland county and the Lisbon basin of Greene, Fayette, Westmoreland and Indiana. Northward, however, these sub-basins disappear, the troughs become very shallow, and at length only isolated tracts of coal remain, as at Blossburg, in Tioga county, on the narrow synclinal ridge crossing into Bradford county.

The fourth basin is bounded by a bold anticlinal crossing the Ohio river just below Pittsburg. It embraces, north from that river, parts of

Armstrong, Jefferson, Elk, Cameron, Potter and Tioga counties, the most northerly exposure of coal being on Driftwood creek in the last-named county.

The fifth basin is bounded at the west by the Brady's Bend anticlinal, which is persistent to the northern line of the state. It embraces portions of Allegheny, Armstrong and Clarion counties, and crosses southeast McKean into Potter county, where the Coal Measures appear in small areas of insignificant value.

The sixth basin embraces the rest of northwest Pennsylvania, and may be regarded as including all that remains of the bituminous region in Pennsylvania and Ohio, for beyond the Brady's Bend axis the folds are petty and without great extent along the strike.

### *RELATION TO MARYLAND AND VIRGINIA COAL AREAS.*

Practically, the last four basins become one at the south. Certainly the third and fourth may be regarded as one at but a little way southward beyond the West Virginia line, while at 50 miles south from the Baltimore and Ohio railroad, in that state, the first and second have coalesced with each other and with the third, owing to the steady depression of the anticlinals in that direction. So, then, what are the conditions in these basins?

Along a line drawn from central Ohio eastwardly through southern Pennsylvania to the Cumberland coal basin, one finds gentle dips, rarely exceeding one or two degrees, until the Coke basin is reached at, say, 50 miles southeast from Pittsburg, where they become steeper, reaching 4° or 5° in the bottom of the trough, and becoming 10° to 12° on the side of the Chestnut hill anticlinal. Eastward no material change in rate of dip is found until beyond the Alleghany mountain, the westward dip in that monoclinal seldom exceeding 10°. To all intents and purposes, the dips in the first and second bituminous basins, as well as in the first subdivision of the third, are the same; the last, however, the most westerly, shows a higher dip in the bottom of the trough than is seen in the others. But in the strip between the Alleghany and the North or Kittatinny mountain the folds are numerous, often bold anticlinals cut into monoclinals, showing Lower Silurian or even Cambrian rocks in the intervening valleys, while still further toward the Blue ridge, in the Great valley, inverted folds are by no means rare.

### Extent of Deformation of the several Coal Basins.

If, however, one study the conditions on either side of this line he will find that it is by no means representative of the conditions for any extended area north or south from it. Northward, in all of the basins

the folding diminishes and the axes are insignificant long before the plateau area of northern Pennsylvania and southern New York has been reached; the structure becomes simpler as the evidences of disturbance become less in that direction. Thus, between the Alleghany and the Kittatinny, the many and great folds of Maryland and of the southern counties of Pennsylvania become fewer and less bold, the synclinals broader and deeper; so that instead of the single area of Coal Measures, that of Broad Top (itself due to the northward decrease of three strong anticlinals), one finds the several anthracite fields in northeastern Pennsylvania. The same general statement holds good with respect to the other basins. Southward the condition is similar except in the strip east from the Alleghany mountain, and yet the difference is very noteworthy. The degree of disturbance in the region west from the Alleghany steadily decreases southward along the strike, and the basins soon become merged; at least, the folds limiting them become so gentle as to be followed with some difficulty. Even the magnificent anticlinal representing the Alleghany alongside of the Cumberland coal-field in Maryland, after attaining its maximum in Randolph county of West Virginia, quickly diminishes so as to cause comparatively small interruptions in the dip on the lower New river—just enough to keep the Coal Measures from passing under that stream for a long distance. The contrast between the southern and the northern conditions is very great. At the north the basins are canoe-shaped and become shallower, the bottom rising so that lower and lower rocks appear in succession as the higher ones pass into the air. At the south, in West Virginia, the anticlinals are lowered so that the higher rocks pass over them. Thus the detached prongs of the Upper Coal Measures in southern Pennsylvania become united as the Pittsburg coal bed crosses the diminishing anticlinals. The Chestnut hill anticlinal attains its maximum in southern Pennsylvania, near the old National road, where the upper Chemung, to a thickness of several hundred feet, is exposed at the summit, about 2,500 feet above tide. But at barely 40 miles away, in West Virginia, the Pottsville crosses this fold at 989 feet above tide, while at 20 miles further the Pittsburg coal-bed also crosses the axis at a slightly greater altitude. The depression of the fold in this interval is not less than 2,300 feet. It is probably much more, because the Carboniferous groups thicken rapidly in that direction. There is then a decrease of disturbance southward toward the border of Kentucky and Tennessee in these so-called bituminous basins.

The conditions in the strip between the Alleghany and Kittatinny mountains are quite different. Extensive coal areas exist further northward, measured along the strike, than in the other region, for the great eastward curve of the Blue ridge in the northerly portion makes possible broader and less abrupt folds; but from central Pennsylvania southward

the strip becomes narrower and the folding more abrupt. Faults become more markedly characteristic until in central and southern Virginia they are to be looked for as the natural explanation of irregularities on the eastern side of the strip. So much is this the case that one cannot well draw a line by which to separate in southern Virginia the two areas of Pennsylvania between the Alleghany mountain and the Blue ridge. The Pocono coals are exposed again and again by the faults even in the Great valley, while the Coal Measures, in what must be taken as equivalent to the anthracite strip of Pennsylvania, are involved for long distances in the faulted areas. The extent of the disturbance in Virginia is much greater than at any locality in Pennsylvania, the faulting sometimes exceeding 12,000 feet.

It is sufficiently clear that to generalize from the conditions of structure observed along the line from central Ohio across southern Pennsylvania, without careful consideration of the conditions both north and south from that line would be dangerous, as liable to lead to serious error.

## Anthracite of Arkansas.

Variation in proportion of volatile combustible matter, such as is observed in Pennsylvania, occurs in other regions. The one of most interest in this connection is that of western Arkansas.

The existence of anthracite or semi-anthracite in western Arkansas was announced by Dr. D. D. Owen* thirty-five years ago in his description of the coal mine at Spadra, in Johnson county. Additional notes respecting the coals of Johnson county were given in a later report;† but Dr. Owen's study of the coals was merely such as could be made during a preliminary reconnoissance, so that the relations of these beds to those in counties further west or in the area immediately beyond, within Indian territory, were not determined.

The first distinct statement respecting the succession of the Coal Measures in western Arkansas was given by Mr Winslow.‡ He found about 3,750 feet of measures, which he separates into three divisions:

| | |
|---|---|
| The Western or Upper Coal-bearing Division, consisting of sandstone and shale | 3,000 feet. |
| The Intermediate Barren Division, consisting of shale and sandstone | 500 feet. |
| The Eastern or Lower Coal-bearing Division, consisting of dark fissile shale | 250 feet. |

*Owen: First Report of a Geological Reconnaissance of the northern Counties of Arkansas, 1858, p. 130 et seq.

†Owen: Second Report of a Geological Reconnaissance of the middle and southern Counties of Arkansas, 1860, pp. 84–85.

‡Annual Report of the Geological Survey of Arkansas for 1888, vol. iii. The Geology of the Coal Regions, by Arthur Winslow, pp. 10–26.

The coal-beds of the upper division are thin and variable, but one, near the bottom, is mined at many localities between the state line at the west and Johnson county at the east. The Intermediate division is practically barren, though occasionally a bed develops into local importance. One opening in northeast Franklin county yields a coal whose composition is not without interest in a discussion of some hypotheses. The Lower division contains a persistent bed near the bottom which is mined in Johnson and Pope counties.

Dr. Owen gives results of analyses of coals collected by him, but they differ so radically from those obtained by Professor Brackett for the recent Geological Survey of Arkansas and given in Mr Winslow's report that the two series cannot be compared.*

The results of analyses presented by Mr Winslow are instructive in view of some theories which have been offered to account for the variation in volatile in the coals of Pennsylvania and elsewhere, and reference to them will be made more than once in the pages to follow. The distance from the state line to the last mine at the east, represented in the analyses, is not more than 64 miles, and there is an intermediate space of nearly 26 miles between the first group of analyses near the state line and the second group in the more easterly counties; yet the illustration suffices for the purposes of this discussion. Arranged in geographical order, the results show—

First. That the coal of the upper division contains more of volatile combustible matter than does that of the lower division, even where the localities are but little separated.

Second. That, in a general way, the decrease in proportion of volatile combustible is in an easterly direction.

The latter statement must be made in this qualified manner. The lowest percentage of volatile is in the eastern counties, but the decrease in that direction is by no means regular. The analyses are numbered from the highest volatile to the lowest, number 27 being the semi-anthracite. I have arranged those which are nearly on the same line according to their geographic position, giving under each its approximate distance in miles east from the state line.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper division: | | | | | | | | | | |
| Numbers | 4 | 12 | 19 | 1 | 16 | 8 | 14 | 15 | 3 | 18 |
| Miles | 2 | 5 | 10 | 11 | 13 | 24 | 26 | 38 | 40 | 41 |
| Intermediate division: | | | | | | | | | | |
| Number | | | | | | | | | | 5 |
| Miles | | | | | | | | | | 39 |

* The difference must be due to the metnod of sampling. The remarkable purity of the Spadra coal, as shown by the Owen analyses, suggests that only hand specimens were used, whereas the results obtained by Professor Brackett indicate careful sampling.

Lower division:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Numbers | 24 | 23 | 26 | 22 | 25 | 21 | 27 |
| Miles | 40 | 42 | 50 | 51 | 56 | 70 | 72 |

Despite these anomalies, which tell us that much remains to be learned respecting the variations in these coals, there can be no doubt that the proportion of volatile is less at the east than at the west, and the contrast becomes more marked if the comparison be made with the western extension of this field in Indian territory, for there the percentage of volatile rises to 30, giving a fuel ratio of 2.11, whereas the lowest ratio given by Mr Winslow for Arkansas is 3.51.

Mr Winslow calls attention to the fact that the decrease in volatile is in the direction of decreasing disturbance in the rocks; that in the western counties there is a system of flexures recalling the Pennsylvania conditions, but no such system exists in the anthracitic counties where "there are very few folds of any kind and a nearly horizontal stratigraphy characterizes the coal areas."

## Anthracite Field of Donetz, Russia.

A brief reference may be made to the anthracite field in southern Russia west from the Donetz river which Murchison* has described. If one follow any of the zones along the strike from the tracts where limestone abounds, he finds the calcareous matter thinning out toward the east, and with this alteration comes a great decrease in the "carbonaceous matter," the bituminous coal disappearing and its place being taken by anthracite. In proceeding from north by west to south by east through the hilly steppes north from Novo Tscherkash one finds the limestone thinning out to insignificant bands, while the sandstones and shales become hard. With these changes in the associated rocks the coal seams become less and less bituminous until they assume all the characters of pure anthracite.

Murchison notes that the line of the anthracite coal coincides with that of the crystalline axis of the southern steppes.

## Variation in the volatile Combustibles in Pennsylvania Coals.

The apparent law of variation in volatile combustible material so attracted the attention of Pennsylvania geologists that efforts have been made more than once to formulate a satisfactory hypothesis, accounting not for the origin of anthracite as such, but for the origin of the Pennsylvania anthracite, associated, as it is, with all intermediate grades and

*Murchison: Geology of Russia and the Ural Mountains, vol. i, pp. 100, 101.

forming a regular series to bituminous coal with very high percentage of volatile.*

### *HYPOTHESES AS TO CAUSES OF VARIATION.*

*Rogers's Hypothesis.*—The first elaborate discussion was that presented by Professor H. D. Rogers† at the third meeting of the American Association of Geologists. He states that "there prevails a very interesting law of gradation in the quantity of the volatile matter belonging to the coal, as we cross the Appalachian basin from the southeast to the northwest." This law involves "a progressive increase in the proportion of the volatile matter, passing from a nearly total deficiency of it in the driest anthracites to an ample abundance in the richest coking coal." This conclusion is based upon "a multiplied chemical analysis" and is regarded as applicable to the whole region between the northeastern termination of the Coal Measures in Pennsylvania to the latitude of Tennessee.

He describes the several basins and discusses the character of the coal in each.

First. "The southeastern chain of basins," answering practically to the region between the Alleghany and the Kittatinny, but embracing at least part of the Great valley in Virginia. Here he finds the coal to be anthracite for the most part, with some slightly bituminous fields as Broad Top and the areas in Virginia, the volatile varying from 6 to 12 or 14 per cent.

Second. The well defined range of basins immediately northwest of the Alleghany mountain in Pennsylvania, the Potomac basin in nearly the same line and the coal-fields of Big and Little Sewell mountains on the Kanawha and lower New river of West Virginia. The undulations are broad and gentle, the region being west of steep flexures and beyond all considerable dislocations. The volatile varies from 16 to 22 per cent. This includes the first and second bituminous basins of Pennsylvania.

Third. The great Appalachian basin, which includes the third and remaining bituminous basins in Pennsylvania, as well as their southern

*Professor Persifor Frazer has shown (Trans. Amer. Inst. Mining Engineers, vol. vi, ) that it is impossible to compare coals unless the impurities be ignored. He recommended a return to the method used by Professer Johnson many years ago, in which the ratio between the volatile and the fixed combustible matter was used as the basis of comparison. The formula is $\frac{C}{V\ H - C}$ the fixed carbon divided by the volatile hydrocarbon. Thus the grouping becomes—

| | |
|---|---|
| Hard dry anthracite | 100 to 12 |
| Semi-anthracite | 12 to 8 |
| Semi-bituminous | 8 to 5 |
| Bituminous | 5 to 0 |

† Rogers: Reports of the First, Second and Third Meetings of the Association of American Geologists and Naturalists, 1843, p. 470 et seq.

extension in West Virginia, Ohio and Kentucky. The folds are gent'e and the bituminization increases northwestward from 31 per cent. at th southeast to 40 or 43 per cent. near the western side of Pennsylvania and on the Kanawha river in West Virginia.

The variation in degree of bituminization of the coal in different portions of the region is attributed to the prodigious quantity of intensely heated steam and gaseous matter escaping through crevices necessarily produced during the permanent bending of the strata. The elevation of the coal rocks must have been accompanied by the escape of an immense amount of hot vapors, whose influence cannot be overlooked upon any hypothesis of the rending and elevation of great mountain tracts. The coal throughout the eastern basins, if thus effectually steamed, would discharge more or less of its volatile constituents as the strata were more or less violently undulated by earthquake action. The more western beds, more remote from the scene of violent action, less crushed and broken, would be less extensively debituminized.

The entire absence of true eruptive rocks in the anthracite fields, which might have caused the change, is a circumstance which lends great support to this theory. The bitumen in the coal augments westward, precisely as the flexures diminish. No such law of gradation could result from transmission of heat from the general lava mass below the crust, for that would involve a corresponding increasing gradation in thickness of crust westward, which is in conflict with the diminishing thickness of Appalachian rocks westward and contrary to correct geothermal considerations.

Professor Rogers resumed the discussion in his final report,* and gave additional matter respecting the variation of volatile in the anthracite basins. The increase of volatile is not along a northwest and southeast line, but along an east and west line, "or, perhaps, more exactly, toward the west-northwest." The occurrence of semi-anthracite as well as of semi-bituminous coal in the Southern anthracite field is described. The absence of semi-bituminous in the other anthracite fields is accounted for by the fact that they do not extend far enough to the westward, reaching, as they do, barely to the line of semi-anthracite in the Southern field. There is a decided increase in volatile westward in these fields.† The intensely anthracitic condition at the easterly end of the basins is accounted for by proximity to the region of dikes, which are especially numerous between the Delaware and Schuylkill rivers, but less abundant between the latter stream and the Susquehanna. Professor Rogers calls attention to the cracked or jointed condition of the coal as affording means for rapid escape of the gases.

* Rogers: The Geology of Pennsylvania, vol. 2, 1858, p. 995 et seq.

† This, it must be remembered, is in the direction of trend.

*Owen's Hypothesis.*—The occurrence of anthracite coal in Arkansas among undisturbed rocks and at 60 miles away from the nearest igneous rocks led Dr D. D. Owen* to surmise that the heat necessary for the conversion of bituminous coal into anthracite must have been derived from "granite and other hypogene (nether-born) rocks" near enough the surface to have permeated the strata with heated vapors or gases, which expelled the greater part of the gaseous matter, or else the coal has been subject to some extraordinary chemical agency by which $CH_4$ has been removed. He cannot think that the Spadra coal, so different from that only a few miles further west, can owe its present composition to any difference in the vegetation. Its "peculiar fissured structure favors the idea that the volatile matter has been expelled by a process more rapid than can be attributed to slow chemical changes, unaided by an elevation of temperature."

*Stevenson's Hypothesis.*—In 1877 J. J. Stevenson,† discussing the variations of volatile shown by the Pittsburg coal-bed in southwestern Pennsylvania and the adjacent portion of West Virginia and Maryland, antagonized the theory that debituminization of the coal toward the southeast is due to increased disturbance in that direction. He showed that there is practically no increase in extent of disturbance from the first subdivision of the third bituminous basin southeastward to the first bituminous basin, so that heat due to the transformation of mechanical force cannot be regarded as the cause to which the debituminization is due. He gave illustrations of noteworthy changes in structure of the coal-bed eastward in the several basins, and concluded that the difference in volatile is due to difference in conditions under which the coal was formed.

*Lesley's Hypothesis.*—In 1879 Professor J. P. Lesley‡ inserted a discussion of this question into Mr A. S. McCreath's second report on the chemical work of the survey. In this he tabulated the analyses presented by Mr McCreath in the previous pages and, after comparing them, offered some suggestions, each of which deserves serious consideration.

He suggests, first, that the percentage of fixed carbon ought to increase with depth of the coal beneath the surface, for the earth's temperature increases one degree Fahrenheit for every 50 or 60 feet of depth. In western Pennsylvania, however, under present conditions, the effect of this increment in temperature must be insignificant, as the lowest coal-bed, the Sharon, is but 1,600 feet below the Washington, the highest of

*Owen: First Report of a Geological Reconnaissance of the northern Counties of Arkansas, 1858, p. 131.

†Stevenson: Second Geol. Survey of Penn., Report of Progress in the Fayette and Westmoreland District, etc., part i, 1877, p. 61 et seq.

‡Lesley: Second Geol. Survey of Penn., Second Report of Progress in the Laboratory, etc., 1879, p. 153 et seq.

the considerable beds, while the latter is but 1,100 feet below the highest stratum recognized in that portion of the Appalachian basin. Considering the whole of this 2,700 feet of rock upon the Sharon, that bed should have a constant temperature of not far from 100° F. in Washington county of Pennsylvania or about 30 degrees more than that of the Washington coal-bed when it underlay the 1,100 feet. Comparing the fuel ratios he finds in the two coals—Washington, 1.19; Sharon (block), 1.52—a difference of 0.33 in favor of the lower bed, which may be due to greater depth of cover or to difference in botany or to our having too few analyses for obtaining trustworthy ratios or to other unknown or unsuggested causes.

He calls attention to the fact that our knowledge is incomplete respecting the extent of the Coal Measures section; that we know nothing respecting higher measures once existing in southwestern Pennsylvania, but now eroded and swept away. In the deeper anthracite basins the Coal Measures, above the Pottsville conglomerate, are 3,000 or more feet thick; and the type of the topography shows that still higher rocks must have existed, though now they have been removed. He discusses the distribution of the Permian beds, and considers that they must have increased eastward, as do the other members of the series, so as to make the top covering very thick in the anthracite fields and thinner in the bituminous fields. In such case the coal-beds will appear to have been subjected to more earth-heat in the east and to less earth-heat in the west, and their carbon ratios (so far as this cause is supposed to operate) will be presumably higher in the east than in the west, as it undoubtedly is.

A second suggestion arises out of the hypothesis that anthracite is due to greater oxidation of the vegetable matter. Why should the beds of the anthracite basins be more oxidized than those of the bituminous fields? The rocks in the undisturbed western fields consist largely of clay, while those of the eastern fields consist more largely of sand and gravel strata, so that oxidation would be more favored in the latter. More, the undisturbed clays of the west lute down and almost hermetically seal the underground coals; the disturbed, semi-metamorphosed and cracked-up clay-slates of the east expose their coals throughout to percolation, evaporation and oxidation. The regions differ in—

1. Heavier covering of Permian at the east, raising earth-heat of the anthracite beds.

2. Greater constitutional looseness of whole pile of deposits in the east, facilitating percolation and oxidation.

3. Universal fracturing of the whole pile at the east, facilitating the exit of the volatile hydrocarbon.

Professor Lesley suggests, in addition, the factor of pressure and that of plant variation. All of these suggestions were offered merely as suggestions, not to formulate any hypothesis, but that others may be led to a careful consideration of the matter.

### Discussion of Hypotheses based on Necessity of Metamorphism.

Rogers and Owen regard anthracite as due to metamorphism and Lesley appears to favor the same theory of origin. Each of these geologists presents a hypothesis respecting the origin of the heat causing the metamorphism.

#### *ANTHRACITE CAN BE FORMED BY CONTACT WITH HEATED ROCK.*

Unquestionably, heat is sufficient, under proper conditions, for the conversion of bituminous coal into anthracite. The localities in which that conversion has occurred are too numerous to admit of question in this connection.

*Examples of Contact-alteration in New Mexico.*—Newberry, Le Conte, Hayden and Stevenson have referred in various publications to the small Placer coal-field about 25 miles south from Santa Fé, New Mexico. There the conditions are perfectly clear. The coal is bituminous near Galisteo creek, but is found becoming less and less so as one ascends the arroyos (dry water-courses) leading up the mountain side, until at length it is an anthracite, with 13 as its ratio. The change was produced by an enormous trachyte dike, which cuts all the beds along the northerly face of the mountain, but the extent of change becomes distinctly less as distance from the dike increases. This little field gives a positive illustration that something more than the mere contact with molten rock is needed to cause metamorphism, for in an arroyo leading up from Galisteo creek a narrow dike of basalt has cut two thin beds of coal, which appear to be unchanged even at the contact, for pieces taken thence burned with abundant flame.* Many canyons in the Trinidad coal-field of northern New Mexico show coal converted into coke † by intruded sheets of basalt. No anthracite has been observed in this field, but the coke is usually denser than that obtained in Belgian ovens. Fragments of graphite have been reported from one exposure on the Upper Canadian river.

*Example of Contact-alteration in Colorado.*—The Elk mountains of central Colorado hold an area of anthracite which was described by W. H. Holmes ‡ and Dr A. C. Peale § in 1876, the exposures having been ex-

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* Stevenson: U. S. Geograph. Surveys west of the 100th Meridian, vol. iii, 1881, suppl., p. 332.
† Loc. cit., pp. 204, 208, 216, 268.
‡ Holmes: Ann. Rep. of the U. S. Geol. and Geog. Survey of the Territories for 1874, p. 67.
§ Peale in same, pp. 98, 99, 139, 176.

amined by them in 1874. Those observers regard the change as due to the influence of eruptive rocks.

*Examples of Contact-alteration in Virginia and North Carolina.*—The well-known conditions in the coal-fields of eastern Virginia and of North Carolina render those areas equally illustrative. Dikes passing across the coal in Virginia have changed it in many places into coke, which at one time was sold in eastern markets under the name of James river carbonite. Anthracite has been formed under similar circumstances at some localities in North Carolina.

*Examples of Contact-alteration in New Zealand.*—Dr Haast * made many references to the occurrence in New Zealand of coal altered by contact with dolerite; sometimes coked, at other times changed wholly into anthracite. In the same report Dr Haast tells of the Hesse Cassel brown coals, altered by basalt sheets, which in many cases form both roof and floor of the seams. Occasionally, where the flow was small, the effect is insignificant. The mode of change is well exhibited near the Meissner, where the mines have been worked for two hundred years. The seams, for the most part, are from 20 to 30 feet thick, and are changed only in part. The effect of the heat extends from 7 to 17 feet, according to the thickness of the overlying basalt. Immediately below that rock, for from 1 to 4 feet, the change into anthracite is usually complete, but thence downward the passage is gradual to the wholly unchanged brown coal. Dr Haast describes a condition very like that observed in our own Placer field, a coal-bed in contact with a dolerite dike is changed into anthracite, but the change becomes less as distance from the dike increases, until the normal "pitch coal" is reached. Dr Hector in the same report adds some interesting notes † to Dr Haast's observations.

*Alteration through Contact not invariable.*—While it seems to be sufficiently clear that bituminous coal can be converted into anthracite by the agency of heat, it must be remembered that there are localities where intrusions of lava have been without influence, and that there are others where, as will be shown, notable folding and crushing have been ineffective, and that there are others where close proximity to granite and other crystalline rocks has led to no change.

### *OBJECTIONS TO ROGERS'S HYPOTHESIS.*

Two fundamental assumptions in the hypothesis offered by Professor Rogers are erroneous: First, that anthracite is necessarily due to metamorphism, and, second, that the plication of the Appalachian region was

* Haast: Geol. Survey of New Zealand; Reports of geological Explorations during 1871-'72, pp. 51, 52, 54, 82.

† Hector: Loc. cit., p. 147.

cataclysmic and deep-seated. Nothing need be said at this stage respecting the former, but reference to the latter is necessary.

*Appalachians not cataclysmic in Origin.*—Possibly the writer may have been wrong in imagining that the plication advanced so slowly as not to interfere with the main water-courses,* but the drainage in Pennsylvania, Maryland, Virginia and West Virginia certainly suggests that the more important streams antedated the folds, for they cross and recross the great anticlinals, synclinals and faults by gaps, in whose walls the rocks are true to dip and strike. Another explanation is possible without calling in the aid of cataclysms. The plication was not so slow everywhere as to permit readjustment of the rock particles without crushing. The great Pocono sandstone in Fulton county of Pennsylvania, more than 1,000 feet thick, was broken into enormous wedges, which were moved one on the other until the contact surfaces were polished, the irregular crevices remaining being filled afterward by thin films of quartz, sufficiently distinct wherever the sandstones are exposed.† The Utica shale in the Great valley of Pennsylvania, as shown in the approaches to the tunnels of the South Pennsylvania railroad, is crushed into lenticular fragments, now polished and closely packed together. In some of the Broad Top mines the coal has suffered similar treatment, with the same result. Such crushing occurs rarely in the less sharply folded area west from the Alleghany, but even there is not altogether wanting, for the coal is often prismatic and jointing is frequently so extensive as to injure sandstone for building purposes.

But G. K. Gilbert ‡ asserts that this crushing cannot extend deeply; that there is little possibility of its reaching downward even to ten miles; certainly, then, the fissuring would not be deep enough to afford escape for heated vapors and gases from the interior of the earth.

The plication, resulting in the Appalachian revolution, began at an early date, as is evident from existence of canoe-shaped synclinals, dating back to the middle Coal Measures, and of subaërial erosion, sometimes of great extent in Ohio and Pennsylvania Coal Measures. Indeed, the folding began far back in geologic time, and the Appalachian basin, closed, it may be, only by a long bar at the west during the Devonian, was crumpled in the latter part of that age just as it was during the early and middle Carboniferous, though less extensively.§

* Stevenson: Proc. Amer. Philos. Society, vol. xviii, 1879, p. 306.

† Stevenson: Proc. Amer. Philos. Society, vol. xxi, 1884, p. 165.

‡ Gilbert: Bulletin of the Geol. Soc. of Amer., vol. i, 1890, p. 27.

§ For facts referred to in this paragraph see Newberry: Geol. Survey of Ohio, vol. 2, part 1, 1874, p. 117; M. C. Reid: Geol. Survey of Ohio, vol. 3, part 1, 1878, p. 572; Stevenson: Annals Lyc. Nat. Hist. N. Y., vol. x, 1873, p. 235; also in Second Geol. Survey of Penn., Fayette and Westmoreland District, part 2, 1878, pp. 271–282.

*Erroneous Conclusions as to Relation of Disturbance to Amount of Volatile.*— The first serious error in Professor Rogers's discussion is in reference to the relation of increase in dip to decrease in volatile combustible matter. He believed that the increase in rate of dip is steady and marked along a west-northwest and east-southeast line. True, the dip does increase from Pittsburg along that line to the Cumberland (Potomac) basin in Maryland; and the increase is remarkable if one compare the extremities of the line; but the increase is not regular. As was stated on a previous page, the increase is moderately great from Pittsburg to the foot of Chestnut ridge in the Connellsville basin, from 1° at Pittsburg to 10° on the side of Chestnut ridge; but there is no further increase until beyond the Alleghany mountain, for in that monoclinal one rarely finds a dip of more than 10° near the line under consideration; but immediately beyond the Alleghany one comes to great folds, with dips of from 20° to 50°, sometimes with inversions. The dip on the easterly side of the Cumberland basin (the Mount Savage synclinal) within Bedford county of Pennsylvania is sometimes more than 80°.*

Along the line chosen by Professor Rogers the Pittsburg coal-bed shows the following variations, the results being the average of analyses in each basin and the calculations being made without reference to water and ash: Pittsburg, 40.7; in the next trough eastward, 39.2; in the Greensburg, 35.3; in the Connellsville or Coke, 33.8; there the dip is from 4° to 6° in the mines; in the Ligonier valley, 28.1; in the Salisbury basin of Somerset county, 23.3; in the Cumberland basin of Maryland, 18.8. The decrease in proportion of volatile matter is greater in passing from Connellsville to Salisbury, about 34 miles along the dip, with *no* change in type or extent of disturbance, than it is in passing from Pittsburg to Connellsville, about 32 miles, with *great* change, or from Salisbury to Frostburg, in the Cumberland basin, about 15 miles, with the *extreme* change in extent and type of disturbance on both sides of the Cumberland basin.

It is very true that, along a similarly east-southeast and west-northwest line across the anthracite fields, a great increase of complexity is observed toward the east. The area of greatest disturbance is in the Great valley beyond the Southern anthracite field; folding is much more marked and the distortion is much greater in that field than in the others; the flexures become broader and gentler toward the northwest, so that in the Northern anthracite field one finds a typical canoe basin, with only moderate dips, while the Loyalsock or Bernice, still further northwest

*Second Geol. Survey Penn. Rep. on Bedford and Fulton Counties, 1882, p. 104. For notes respecting the conditions in West Virginia, see I. C. White: Proc. Amer. Philos. Society, vol. xix, 1881, p. 438 et seq.

(the northern termination of the first bituminous basin), though containing anthracite coals, has dips varying from 3 to 5 feet per hundred.* But, as will be shown later on, this increase in complexity bears no relation whatever to the character of the coal in the several anthracite fields.

*Neglect of Conditions observable in the individual Basins.*—A notable source of error in the discussion lay in neglect of the conditions observable along the trend in the several basins. From Pittsburg east-southeast to Frostburg, in the Cumberland basin, one finds the conditions already noted, with greatly increased disturbance beyond that basin. But let it be remembered that the extent of disturbance diminishes northward in all the basins; that the folding in and around the Middle and Northern anthracite fields is less than that in and around the Broad Top of southern Pennsylvania and the Cumberland in Maryland; that the flexures in the Loyalsock are less pronounced than those in Somerset county of Pennsylvania, in the southern portion of the same first bituminous basin.

*Discontinuity of Rogers's Line connecting anthracite and bituminous Basins.*—A still more serious error was that of extending this single line beyond the Cumberland basin across the anthracite fields. The line from Pittsburg to Frostburg or to the Broad Top field is not continuous with that across the anthracite fields; its eastern portion is parallel to the latter line, and is equivalent to the line passing through the Northern and Middle fields. There is no certainty in the impression that if the line were continued beyond the Broad Top field or the Cumberland basin anthracite conditions would be reached.† As has been stated on a former page, the Broad Top coal-field may be taken fairly as representing the Northern field.

*True Statement of Relation of Disturbance to Amount of Volatile.*—The true statement is that the decrease in volatile combustible matter, as shown in the easterly basins, is not merely toward the east, but also and more notably toward the north, along the trend, and apparently without any relation whatever to the degree of the disturbance; for in the former case the decrease is in the general direction of increase of disturbance; in the latter, the decrease is in the general direction of decrease of disturbance. Not to multiply details here, as they will be needed in another part of this discussion, it suffices to emphasize two facts: The driest anthracite is not found in the Southern anthracite field, which contains the most

*Ashburner: Ann. Rep. Second Geol. Survey Penn. for 1885, pp. 283–284.

†This statement is made cautiously, for in northern Virginia the Pocono coals, lying in a line with the Southern anthracite field, sometimes approach anthracite, but the ratios show extreme variations.

folded and distorted basins, but in the Middle fields. The hardest anthracite is not found in the southwesterly or most plicated portion of the Southern field. There semi-anthracite, even semi-bituminous, occurs, while the harder anthracite is obtained at the other end of the field, where the condition is becoming more like that of the other anthracite fields.

*Influence of Dikes insignificant.*—It seems hardly necessary to refer to the supposed influence of dikes in causing the greater hardness of coal at the northerly end of the southern basin. It is well known that such influence can be exerted to but a little distance. The coal-fields near Richmond, Virginia, have been intersected by dikes sufficiently to test this matter; but there are few coals richer in volatile conbustible than those near Richmond. The dikes in northeastern Pennsylvania are extensive, but they could not be a factor in this matter.

*Columnar Structure not Evidence of loss of Volatile through Consolidation.*—Columnar structure gives no evidence in favor of the supposition that the coal has been subjected to the loss of volatile after consolidation. The Imboden coal of Wise county, Virginia, with about 37 per cent; the Pocahontas coal of Virginia, with 21 per cent; the Pittsburg coal on Scotts run, in Monongalia county of West Virginia, with nearly 40 per cent, and the same coal near Uniontown, Pennsylvania, with 36 per cent of volatile, all have this structure almost equally well marked.

### *OBJECTIONS TO HYPOTHESIS OF MURCHISON AND OWEN.*

Murchison notes that the line of the anthracite coal in the field west from the Donetz river, Russia, coincides with that of the crystalline axis of the southern steppes, and suggests that the igneous rocks of that axis in their subterranean prolongation may have converted the superficial coal into anthracite while hardening the grits and sandstones and shale; but there is need of proof that granitic and schistose rocks have any metamorphosing power. The change in those rocks must have been complete that they might be available as hypogene rocks to support the coal. Certainly the coal-fields of eastern Virginia occupying basins in the metamorphic rocks show no change due to the influence of those rocks. It is much more likely that the crystalline axis of the steppes formed the shoreline of the region from which the coal marshes extended into the basins. The change in type of rock and the disappearance of the limestones in that direction go to show the proximity of a shoreline.

Dr. Owen's explanation is of the same sort. No rocks of igneous or of metamorphic origin are to be seen anywhere near the coal-field; but

their presence is necessary to the hypothesis that the coal is metamorphic, and they are supposed to be at no considerable distance below the surface.

### *OBJECTIONS TO LESLEY'S HYPOTHESIS.*

*Increased Rock-covering not productive of increased Heat.*—Professor Lesley suggests that the increased thickness of overlying rock might lead to increased heat in the lower beds. He illustrates his point by comparison of analyses of coal from the Washington and the Sharon beds, the two available extremes of the column in western Pennsylvania; but the comparison is insufficient, since comparison of the Washington coal with coal from the Mercer and Quakertown beds, belonging at approximately the same horizon with the Sharon, gives a contrary result.*

*No increased Rock-covering in Anthracite Region.*—Professor Lesley, accepting this suggestion as a possible explanation of varying percentages of volatile combustible matter, applies it to explain debituminization of the coals of eastern Pennsylvania. He maintains that as the Paleozoic groups thicken toward the east, there is every reason to suppose that the Permo-Carboniferous, existing in southwest Pennsylvania and in West Virginia, must have extended into the anthracite region with constantly increasing thickness, so that one should expect to find, as he does find, the coal with very much less volatile there than in the region west from the Alleghany mountain.

The supposition that the coal groups thicken eastward toward the anthracite region is hardly in accordance with the facts, as recorded in the reports of the Pennsylvania survey.† It is altogether true that the Devonian and lower rocks have their greatest thickness at the east, and that they do decrease with great rapidity westward, even within the limits of Pennsylvania; but this is not altogether true of the Coal Measures groups, especially of the higher groups, which lose thickness as they recede from southwest Pennsylvania, north, east and west. This general statement is necessary, for the old conception still prevails too widely that the same law of decrease holds good for the Coal Measures as for the lower groups; but the conditions had changed at the end of the Devonian, so that the Cincinnati arch at that time, whatever it may have been during the Devonian, had become more than a bar, had become a low upland, with drainage enough to bring down not very coarse material for the sandstones of the Coal Measures. The Coal Measures were deposited in an almost land-locked basin, along whose central strip lime-

* Second Report of Progress in the Laboratory, etc, 1879, pp. 146–147.

† Many of these were published after Professor Lesley's discussion was prepared.

stones were formed. The old grouping of the Coal Measures in Pennsylvania answers best for comparison. It is, in ascending order—

1. Pottsville.
2. Lower coal group.
3. Lower barren group.
4. Upper coal group.
5. Upper barren group or Permo-Carboniferous.

The Pottsville conglomerate within the anthracite fields varies in thickness, according to Ashburner,* from 551 to 1,280 feet in the Southern field, whereas in the Middle field, near Hazleton, it is but 262 feet, while near Wilkesbarre, in the Northern field, it is but 96 feet. The variations in thickness occur within short distances and are very startling. The causes do not concern us here. In the Broad Top region the thickness of the Pottsville is not far from 250 feet,† whereas on the east side of the Cumberland basin, along the Baltimore and Ohio railroad, in West Virginia, it is 451 feet.‡ Its lower plate disappears in southwest Pennsylvania, where the total thickness is not far from 200 feet.§

The lower coal group,‖ taking the Mammoth bed as its upper limit, shows an extreme thickness of 500 to 437 feet in the Southern field; of 213 to 156 feet in the Middle field and of 476 to 257 feet in the Northern field. In the semi-bituminous Broad Top field the extreme thickness is barely 220 feet,¶ and on the eastern side of the Cumberland basin, on the Baltimore and Ohio railroad, it is only 268 feet.** These are all within the strip between the Alleghany and the Kittatinny mountain—the anthracite strip; but in the bituminous basins the thickness of this group varies from 300 to 350 feet, as given by White, Platt and Stevenson in their several reports.

The lower barren group in Broad Top is about 520 feet, and about 600 feet on the east side of the Cumberland basin. No positive statement can be made respecting its thickness in the anthracite field, as the identification of the Pittsburg coal-bed there is not wholly certain, but it is approximately the same as in Broad Top. In the bituminous areas, according to White, Platt and Stevenson, the thickness varies from 570 to 610 feet.

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* Ashburner: Ann. Rep. Geol. Survey of Pennsylvania for 1885, p. 294.

† Stevenson: Second Geol. Survey of Pennsylvania; Geology of Bedford and Fulton Counties, 1882, p. 65.

‡ I. C. White: Proc. Amer. Phil. Society, vol. 19, 1881, p. 445.

§ The writer long ago became convinced that he should have placed the coal beds underlying the Pottsville conglomerate of southwest Pennsylvania with the Pottsville instead of in the lower Carboniferous. This correction he made in Am. Jour. Sci., vol. xxxiv, 1887, p. 37.

‖ These figures are taken from Ashburner in the Ann. Rep. for 1885.

¶ Geology of Bedford and Fulton Counties, p. 60.

** I. C. White: Proc. Amer. Phil. Society, vol. 19, p. 445.

Thus far, it is sufficiently clear that the comparison affords no basis for the assertion that the Measures are thicker, materially thicker, in the anthracite than in the bituminous regions. It is impossible to make similar comparisons in detail for the upper groups, since they have not been differentiated finally from the lower barren group in the anthracite fields. At the same time, there is no reason to doubt that both the upper coal group and the Permo-Carboniferous are present in the anthracite region, for 2,250 feet of rock are reported * as overlying the Mammoth bed at Pottsville. The Pittsburg bed has been identified with much hesitation in one of the anthracite fields, but there is no doubt respecting the identification in the Cumberland field and but little in the Broad Top field. It is certain, however, that groups 4 and 5 attain their greatest Pennsylvania thickness in the extreme southwest corner of the state, and that in all directions from that locality, within the state, they decrease in thickness. This appears abundantly by comparison of measurements made by Professor I. C. White and by the writer in Ohio and various portions of Pennsylvania.† There is every reason, therefore, to believe that they are less thick in eastern than in western Pennsylvania.

*Increased Rock-covering not found to produce Anthracite.*—Measurements made in Virginia and West Virginia by I. C. White, Fontaine and Stevenson show conclusively that the thickening of the Coal Measures was not greatest, was not even great, in the anthracite region or at any other locality in Pennsylvania. Long ago Fontaine measured the Pottsville group on the New river and announced the thickness to be not far from 1,200 feet. The writer found 1,000 feet in Wise county of Virginia; ‡ while Professor I. C. White measured 1,400 feet at one locality in Fayette county of West Virginia,§ and announced that in Kentucky the thickness reaches 2,000 feet. On the Big Kanawha river of West Virginia Professor White finds the lower coal group 1,006 feet thick, while the lower barren group is 800 feet.|| Still further south, in Wise county, Virginia, many miles beyond the extreme southern limit of the Pittsburg coal-bed, as determined by Professor White, the writer found 2,348 feet of coal measures above the top of the Pottsville,¶ which can represent only the lower coal group and the lower barren group. It is, therefore, unquestionably certain that the thickness in the anthracite fields is very much less than in eastern Kentucky and the southern portion of the

*Ashburner: Second Geol. Survey Pennsylvania; First Rep. on the Anthracite Coal Region, 1883, p. 239.

† Stevenson: The Fayette and Westmoreland District; 1878, part 2, chap. xxi, pp. 283–295.

‡ Stevenson: Proc. Amer. Philos. Society, vol. 19, 1881, p. 230.

§ I. C. White: Stratigraphy of the Bituminous Coal-field of Pennsylvania, Ohio and West Virginia, Bulletin U. S. Geol. Survey, no. 65, 1891, p. 197.

|| I. C. White: Loc. cit., pp. 85 and 140.

¶ Proc. Amer. Philos. Society, vol. 19, p. 238.

Virginias; yet there is no anthracite in southwest Virginia or along the Kanawha river. On the contrary, the Imboden coal-bed, toward the bottom of the lower coal group in Wise county, Virginia, has almost as much volatile combustible as the Pittsburg coal-bed has at Pittsburg.

There are instances within the anthracite strip which tempt one to say that the decrease in volatile is in direction of decrease of cover. The Lykens valley coals of the Southern anthracite field, which have as much volatile as the Bernice coals at the extreme northern portion of the first bituminous basin, belong not to the upper coal groups, but to the Pottsville.

An equally satisfactory illustration is found in the Arkansas field. The upper coal division is about 3,000 feet thick and its important coal-bed is near the bottom. The main coal of the lower coal division is at about 750 feet lower in the column. The upper bed has a fuel ratio of 6.15, while that from an opening in the lower bed, less than a mile away, has a fuel ratio of 7.30. That this difference cannot be explained as due to the influence of additional pressure or of increased earth-heat because of the column of 750 feet of rock is evident from the fact that the coal-bed of the intermediate division is opened almost midway between the two localities, and its coal has a fuel ratio of 4.97, much more volatile than is contained in the upper bed.

### *OBJECTIONS TO HYPOTHESIS OF MECHANICAL FORCE TRANSFORMED INTO HEAT.*

*Mallet's Investigations.*—Mallet's investigations, showing the quantity of heat evolved by the crushing of rock, have been a fruitful source of hypotheses respecting metamorphism. There is no room for doubt that such crushing can produce heat; that it might produce heat enough to convert bituminous coal into anthracite; the difficulty is not in the conception of possibility, but in finding evidence of probability. The presumption in every case is against the supposition that the anthracite, granting that it is the result of metamorphism, was metamorphosed by heat due to this agency. The instances of metamorphism unequivocally due to crushing and folding are none too numerous, whereas instances in which no metamorphism has taken place despite the most violent crushing are sufficiently numerous.

*Evidence of the Virginia Coals.*—The Pocono coals in southwest Virginia have been crushed during the folding and faulting of that region until in some localities they are as flaky as pastry crust. The filmy layers can be separated by the fingers, and their surfaces are polished by the chafing which they have endured; yet that coal is rarely more than semi-anthracite, and in some localities it is a semi-bituminous coal. The Pottsville coal at Quinnimont, West Virginia, is in the gently undulated

Sewell mountain region; yet its volatile is no greater than that of the same coal at Pocahontas, in Virginia, at a little way from the Abb's valley fault, whose throw is more than 10,000 feet. The crushed "looking-glass" coal in the Broad Top field is semi-bituminous, while the uncrushed coal of the gently flexed Wyoming field is anthracite. The Barnet bed in the Broad Top field is faulted, but shows coal of the same quality on both sides of the fault. The Imboden coal-bed of Wise county, Virginia, at only a stone's throw from the great overturned anticlinal of Stone mountain, has about 37 per cent of volatile, quite as much as it has miles away at the west in the undisturbed portion of Kentucky.

*Evidence of the Arkansas Coals.*—Mr Winslow's observations in Arkansas afford another illustration which is in place here. Evidently inclined favorably to the doctrine of metamorphism by heat derived from crushing, he regards as somewhat curious the fact that the volatile combustible in the Arkansas coals diminishes as the distance from disturbance increases, for the region of high volatile is traversed by flexures recalling to mind the systems in Pennsylvania, whereas the region of the semi-anthracite is undisturbed.*

## Metamorphism not a sufficient Explanation of the Phenomena.

While there can be no doubt that bituminous coal, heated by contact with molten rock, or by transformation of mechanical force exerted in crushing rock, or by action of gases or vapors from deep-seated sources, may become anthracite, still it must be conceded that in Pennsylvania there is no evidence showing any relation of cause and effect between such agencies and the loss of volatile combustible in the coal. Some explanation other than that depending on metamorphism must be found; for if metamorphism be unnecessary to explain the variation of volatile from 45 to 35 per cent in the same coal-bed within a few rods, it should be equally unnecessary to explain a still further loss of volatile. The more so, in view of the well-known fact that different benches of the same bed at the same opening, where they are separated by only a few inches of clay, show a contrast greater than that between the Pittsburg coal in the Salisbury bituminous basin and the Stoney creek coals of the Southern anthracite field.† The volatile often differs several per cent in the different benches of a coal-bed. Even in the same hillside in the Bernice or Loyalsock field (the northern end of the first bituminous basin) and barely 60 feet apart are two beds, the lower showing a ratio of 4.13,‡ while that of the upper bed is 10.28.

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* Winslow: Loc. cit., p. 51.

† Ann. Rep. Second Geol. Survey of Pennsylvania for 1885, pp. 480, 482, 485.

‡ A. S. McCreath: Second Rep. of Progress in the Laboratory, etc, pp. 82–94.

## Bischof's Theory of the Formation of Anthracite.

Long ago Bischof recognized that graphite is of vegetable origin, the mode of its occurrence in coal-beds of Greenland as well as in those near Cumnoch, in Scotland, being such as to leave no room for doubt. As anthracite is intermediate between bituminous coal and graphite, its vegetable origin was conceded of necessity. Lesley* has shown by tabulating the analyses made by A. S. McCreath that the series from the driest anthracite to the richest bituminous coal is almost perfect.

Vegetable matter left exposed upon the ground decays; it is oxidized and loses its own oxygen very rapidly. This process does not convert wood into coal, the escaping gases being carbon-dioxide and water; but under water the change advances differently, so that the carbon and hydrogen unite, and marsh gas as well as the other gases mentioned is set free. Goeppert † found that the decomposition of mosses goes on more slowly as the depth of the water increases; those at 6 to 8 inches below the surface decompose rapidly, but others at 12 to 36 inches were fairly preserved for fifteen months. The character of the decomposition may well assume different characters with varying depths of water. Bischof ‡ thinks that the smaller quantity of volatile hydrocarbons in anthracite fields may be due to the more ready access of water, which favored evolution of marsh gas as well as the other gases. Sterry Hunt § has exhibited the several steps in the process of change from cellulose to bituminous coal by a series of empirical formulas, which show the successive conditions mentioned by Bischof. Green || has illustrated the relations of the several products from wood to anthracite by a table of percentage compositions.

## Lesley's Suggestion of Oxidation.

Professor Lesley uses the process of oxidation as the basis of a suggestion respecting the possible origin of the Pennsylvania anthracite. He lays great stress upon the fact that in the anthracite region there are more of sandy and gravelly rocks than in the bituminous regions, where clayey materials abound, so that oxidation of the coal would be favored in the former more than in the latter. He maintains, further, that the undisturbed clays of the latter lute down and almost hermetically seal the underground coals, whereas the disturbed, semi-metamorphosed and cracked-up clay-slates of the former expose their coals to the very bottom of the series to percolation, evaporation and oxidation.

* Lesley in Second Report of Progress in the Laboratory, etc, 1879, p. 146 et seq.

† Goeppert cited by Bischof, Chemical Geology, vol. i, p. 271.

‡ Bischof: Chemical Geology, vol. i, p. 273, foot-note.

§ Sterry Hunt: Chemical and Geological Essays, 1875, p. 181.

|| Green: Geology, 1882, part i, Physical Geology, p. 182.

*OBJECTIONS TO LESLEY'S SUGGESTION.*

*Undisturbed Areas furnish all Varieties of Coal.*—If we had to deal only with the extremes, with the rich gas-coal of the Pittsburg area and the dry anthracites of the Middle anthracite fields, these suggestions would have greater weight; but we must remember that the practically undisturbed or only gently folded beds of the bituminous basins west from the Alleghany mountain yield every possible gradation, from the richest bituminous coals to the semi-anthracites of the Loyalsock (Bernice) field, the latter having in some cases even less volatile than the Lykens valley coals of the Southern anthracite field. In all of these are found the clay-beds which should prevent percolation and the rest; but it is unnecessary to go outside of the anthracite field for an illustration, for in a single colliery on the Mammoth bed in the Southern anthracite field semi-bituminous, almost bituminous, coal occurs in one bench and hard anthracite in another, the ratios being 5.59 and 51.1.*

The Northern anthracite field, as described by Chance and by Ashburner, is not fractured. It seems to be much less disturbed than is the southern portion of the Broad Top semi-bituminous field. Ashburner's sections show a good deal of clayey material. Taken all in all, the conditions in Broad Top appear to be more favorable to percolation and oxidation than are those in the Northern field, certainly far more favorable than those in the Loyalsock field, if extent of fracturing and thickness of clays be the test.

*Influence of Clay-beds insignificant.*—The presence or absence of the clay-beds evidently has very little to do with the matter. Ashburner's sections in the Northern field show more clay-beds than can be found in a greater thickness of rock within the Black mountain coal-field of southwest Virginia, immediately behind the overturned anticlinal of Stone mountain; yet at half a mile from the vertical beds in that fold the Imboden bed shows a fuel ratio of 1.67, while the Kelly bed, at barely a stone-throw from the vertical beds, has a fuel ratio of 1.48. Certainly this area should be cracked-up enough, for its southeasterly boundary is the Stone mountain anticlinal and the faulted area of southwest Virginia, while its northerly boundary is an enormous fault. An even more satisfactory illustration is found in the southeastern prong of the Southern anthracite field, where, within a dozen miles along the trend, the ratio varies from 4.64 to 12.40.

*Process of Conversion completed prior to Rock-consolidation.*—The suggestion immediately under consideration evidently carries with it the additional suggestion that the change was not complete even when the whole

*A. S. McCreath: Ann. Rep. of Second Geol. Survey of Pennsylvania for 1885, p. 321.

pile of rocks had been deposited, and that the process continued until sometime posterior to the folding and crushing; but it is not easy to understand how percolation would be carried on to any greater extent in the anthracite than in the bituminous region after the folding and consequent erosion had taken place. Those who mine bituminous coal find the water of percolation through the coal itself sufficiently troublesome in western Pennsylvania. Water of this kind would be stagnant in the canoe synclinals, and as its oxygen would soon be converted into carbon dioxide, the process of oxidation would be stopped. Bituminous coal, it is true, when exposed to atmospheric moisture and a slightly increased temperature, does undergo changes in composition somewhat analogous to those which lead to anthracite—changes which appear in most cases to be accompanied with deterioration of the coal, physically. The defects of "crop coal" are well known to all; but conditions such as cause change of coal in the atmosphere cannot be conceived of as existing at a thousand feet below the surface, where the supply of oxygen is very small and where what supply there is is fixed very promptly. In fact, there is ground for believing that the changed condition of "crop coal" is due to mechanical even more than to chemical change.

We can determine one point respecting the time of consolidation. The coal of the Upper Freeport, as well as that of the bed first above it in the Broad Top field, was thoroughly consolidated long prior to the date of folding, for in those beds the fragments were rubbed one on the other until they became as thoroughly polished and lenticular as are the fragments of Utica slate in the Great valley further east. The Pocono coal near Christiansburg, Montgomery county, Virginia, was broken during the folding into irregular pieces, which are wedged together just as are the vastly greater fragments of Pocono sandstone in Wray's hill of Bedford county, Pennsylvania.

But the whole process of conversion must have been practically complete before the rocks were consolidated—indeed, before the coal was buried finally, the result of the pressure being to remove the water and marsh gas and to consolidate the coal. The extent of conversion would depend largely upon the length of time to which the peaty material had been exposed to percolation of water. That practically no further change takes place after burial and consolidation, is suggested by the conditions seen in the Laramie coals of New Mexico and Colorado. Within the Trinidad field the coal is anhydrous, rarely containing more than 2 per cent of water; but northward from Colorado Springs the coals of the same period have from 12 to 20 per cent, while along the Union Pacific railroad they have from 6 to 13 per cent in Wyoming and from 1.68 to 10.66 in Utah.* A similar contrast is found between the

* Marvine: Ann. Report of the U. S. Geol. and Geog. Survey of the Territories for 1873, pp. 112, 113.

almost hydrous coals of Iowa and Missouri and the anhydrous coal of Indian territory.

### The Writer's Hypothesis as to Origin of Coal-beds.

But we are not left altogether to suggestion in the effort to explain the origin of the Pennsylvania anthracite as resulting from continuous loss of marsh gas until the final burial and consolidation.

More than twenty years ago the writer, having discovered that the limestones of the Ohio Upper Coal Measures disappear at but a little way west from the Ohio river, was led to assert that the Coal Measures of the Appalachian basin "were not united to those of Indiana and Illinois at any time posterior to the Lower Coal Measures epoch and probably were always distinct." Studies made in the Ohio and West Virginia coal-fields led also to the conclusion that the lower coal-beds had been deposited as fringing marshes,* and that the coal-beds, for the most part, had their origin at the east. It is unnecessary to enter into the details of the theory of the origin of the Appalachian coal-beds presented by the writer in 1872† and amplified in later publications, as they do not concern the matter at issue here. It suffices that on purely stratigraphic grounds the conclusion was reached that the Coal Measures marsh had its origin at the east, and that it extended seaward after each period of accelerated subsidence, so forming a new coal-bed. According to this hypothesis one should find in the northeastern portion of the Appalachian basin not only a greater mass of coal than in any other part of the basin, but also a greater degree of conversion.

### *APPLICATION OF THE HYPOTHESIS.*

*Thickness of Coal greatest in northeastern Portion of Appalachian Basin.*—Let the lower coal group be used first in making comparison of thicknesses in different parts of the basin.

The greatest thickness is found in the Southern and Middle anthracite fields and in the eastern portion of each. The variation in the Southern field is from 106 feet of coal ‡ at the extreme east to 18 feet at the extreme southwest. The average at the east is about 58 feet and for the middle about 53 feet. The thickness for the west end is taken from Taylor, but H. D. Rogers § thinks it too great. The Middle field does not extend so

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* Stevenson cited by Newberry, Geol. of Ohio, 1874, vol. 2, part i, p. 169.

† Stevenson: Annals of Lyceum of Nat. Hist. of New York, 1873, vol. x, p. 252; Proc. Amer. Philos. Society, 1875, vol. xiv, p. 293; Second Geol. Survey of Pennsylvania, Rep. on Fayette and Westmoreland District, part ii, pp. 283–295.

‡ Ashburner: First Rep. of Progress in the Anthracite Coal-field, 1883, p. 45; Annual Report for 1885, pp. 330–339.

§ Rogers: Geol. of Pennsylvania, 1858, vol. ii, pp. 193-195.

far southwestward—that is, along the strike—as does the Southern. The thickness of coal varies from 52 to 53 feet in the eastern Middle, and from 58 to 40 feet in the western Middle, the last thickness being near Shamokin at the westerly end;* but in both the Southern and the Middle the Mammoth bed alone sometimes shows more than 100 feet of clear coal.† The Northern field in the westerly portion shows from 44 to 53 feet. The anthracite region, then, except in the extreme southerly prongs of the Southern field, shows an average thickness of from 40 to 60 feet of coal, the greater thickness being at the northeast.

Going southward or, better, along the trend, in this anthracite strip, the remarkable diminution in thickness noticed in the Southern field is found to be not local, for in Broad Top the thickness of coal does not exceed 14 or 15 feet,‡ and Professor White found the thickness on the east side of the Cumberland basin in West Virginia to be not more than 15 feet, with at least 2 feet of slate.§

In passing from the anthracite strip to the bituminous basins one finds no prong, like that of the Southern field, to show the continuous decrease in thickness; but that is not needed, for the decrease is sufficiently marked. In the first bituminous basin the thickness of the beds of the lower coal group, including all slates and partings, varies from 21 to 23 feet, the greater thickness being at the north; in the second basin the extreme is 19 feet near the Maryland line and 22 feet in Indiana county, while in the third basin and beyond, the thickness decreases until at the Ohio line it varies (all slates and partings being included) from 8 feet 6 inches to 13 feet 4 inches.‖

The lower barren group shows almost equally striking variations, for in the Southern field the interval between coal-beds E and H contains from 25 to 36 feet of coal, partings not included; the western Middle shows 39 feet at the eastern end and 20 at the western end, while in the Northern field this interval has from 17 to 27 feet. The Broad Top field shows not more than 5 feet. No detailed measurement was made by Professor White, owing to lack of exposures, on the east side of the Cumberland basin. Elsewhere in Pennsylvania and Ohio the amount of coal in this interval is extremely uncertain, the average in any single section seldom being more than 4 or 5 feet, though occasionally, as in Guernsey county of Ohio and Somerset county of Pennsylvania, a bed

* Ashburner: Annual Report for 1885, pp. 339, 341. 349, 351.

† Ashburner: First Report on Anthracite Coal-field, pp. 95, 103, 231, 232.

‡ Stevenson: Geol. of Bedford and Fulton Counties, 1882, pp. 60, 235, 259.

§ I. C. White: Proc. Amer. Phil. Society, vol. xix, pp. 440-441.

‖ These measurements are taken from the reports of the Second Geol. Surv. of Pennsylvania by White, Platt and Stevenson.

attains to local importance. The same contrast appears for these groups between the anthracite region of Pennsylvania and the bituminous areas of West Virginia, as Professor White has shown.*

Comparison of sections representing the upper coal group shows that the conditions were changing in the Southern field, for the upper beds are thin, seldom exceeding 2 or 3 feet; the same is true of the western Middle, but in the Northern the change is not so marked, the higher beds comparing very favorably with those of the lower barren group. The greatest thickness in the 400 feet taken as equivalent to the upper coal group of the bituminous areas is 26 to 29 feet in the Northern, 25 feet in the western Middle and 11 to 12 feet in the Southern anthracite field. In the Broad Top field the coal in all, counting partings, does not exceed 7 feet in a section of 260 feet. Tyson † found 36 feet of coal-beds in the Cumberland basin, but his description does not tell how much of this is coal. Professor White. however, found that in the 19 feet 8 inches of Pittsburg coal-bed there are but 14 feet 6 inches of coal. The Salisbury basin of the first bituminous area shows 16 feet of coal-beds in 200 feet of measures, but further westward the thicknesses are so variable that no estimates can be given that would be other than misleading. The variations of the Pittsburg bed, however, can be followed without difficulty. In the Cumberland basin it is 14 feet 6 inches; in the Salisbury basin, 10 feet; in the Ligonier basin, 8 feet; in the Connellsville or Coke basin it is from 6 to 9 feet; in the Greensburg, 6 to 7 feet 6 inches; in the Lisbon, 5 to 7 feet; but beyond that it rarely exceeds 5 feet, the extremes in Ohio along the river being 4 feet 6 inches to 5 feet, while in Guernsey county, on the northwestern outcrop of the bed, its thickness is but 4 feet 2 inches.‡ Professor Andrews has stated that at its last western outcrop the bed is not more than one foot thick. That is its thickness in the center of the Appalachian basin in southern West Virginia.

*Conversion greatest in the northeastern Portion of Appalachian Basin.*—It is evident that the conditions favoring accumulation of coal in beds lasted longer without interruption in the anthracite region than in any other portion of the Appalachian basin, for the amount of coal decreases westward and southward from that region. A comparison of thickness of beds shows a tendency to greater regularity in a northeasterly direction within the first and second bituminous basins; but it is unnecessary and it would be very tedious to enter into the details of this comparison.

* Bulletin no. 65, U. S. Geol. Survey.

† Tyson: Second Rep. to House of Delegates of Maryland, 1862, p. 46.

‡ These measurements are taken from the writer's reports on Pennsylvania and Ohio.

### Relation of increasing Thickness of Coal to decreasing Volatile in Pennsylvania.

Under such conditions one should expect the amount of volatile combustible matter to show marked decrease in the beds as they approach the old shorelines. This decrease is shown by the analyses. In the anthracite strip the ratios are as follows:

| | |
|---|---|
| Cumberland basin* | 4.47 to 4.78 |
| Broad Top | 3.26 to 4.64 |
| Southern anthracite: | |
| Southeast prong (the longer) | 4.63 to 12.40 |
| Southwest prong | 8.91 to 11.30 |
| Main field | 11.64 to 23.27 |
| Western Middle | 19.87 to 24.00 |
| Eastern Middle | 25.53 to 30.35 |
| Northern | 19.33 to 19.92† |

Similar variations are found along the trend in the several bituminous basins. Thus in the first, the Clarion coal-bed shows from 2.94 to 4.84 near the Maryland line, but 5.48 to 6.09 in Lycoming county and 7.07 to 10.28 in Sullivan; the Brookville varies from 2.14 in Somerset to 4.13 and 6.93 in Sullivan. In the second basin, the Upper Freeport is 2.26 and 2.85 near the Maryland border, but becomes 3.96 to 4.48 in Lycoming; and the Clarion changes from 2.25 in Indiana to 3.88 in Tioga. But in the third basin it is not easy to make such comparisons, for the lower coals are buried deeply at the south and the higher coals extend but a little way northward from the Ohio and Conemaugh rivers. At the same time, it is clear that the variation becomes much less in this broad basin than it is in the basins nearer the anthracite region, which is precisely what we should expect. There is, however, a distinct decrease of volatile northward, as shown by the analyses of the Upper Freeport in Beaver, Armstrong and Clarion counties. The result of comparison is to show that the decrease of volatile is found along a line following the trend northward and along the line eastward to which Rogers referred.

### Conclusions.

The conditions, then, are—

First. A decided increase in thickness of the coal series eastward or, better, northeastward toward the anthracite region and a less marked increase northward in the bituminous basins.

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* Analyses of the Pittsburg coal-bed only are accessible.

† These results of analyses are by Mr A. S. McCreath, except those from the southeast prong of the Southern field, which are taken from R. C. Taylor's Reports on Coal Lands of the Dauphin and Susquehanna Coal Company, 1840. Mr McCreath's analyses, for the most part, are in his second report, already quoted so often, and in the Annual Report for 1885.

Second. A decided decrease in volatile in the direction of increased thickness of coal, the decrease being comparatively gradual until near the anthracite fields.

Third. That this decrease is gradual even in the anthracite strip from the Cumberland basin to the semi-bituminous coals of the Southern anthracite field, where the rapid increase in thickncss of coal is accompanied by a rapid decrease in the volatile.

When, in 1877, the writer called the attention of his colleagues on the Second Geological Survey of Pennsylvania to the fact that the decrease in volatile is wholly without relation to increase or decrease of disturbance in the strata, he suggested that the variation was due to difference in conditions under which the coal had been formed in the several localities discussed—a sufficiently comprehensive hypothesis, but yielding in that respect to some others of later date. Now, however, there seems to be no good reason for any such suggestion; all that was needed was longer exposure to the process whereby ordinary bituminous coal was formed. In origin, the anthracite of Pennsylvania differs in nowise from the bituminous coal of the Appalachian basin; but because the great coal marsh, from which sprang the many beds, originated in the northeastern corner of the basin and extended thence on the advancing deltas, formed by streams descending from the Appalachian highlands, the time, during which the successive portions of the marsh would be exposed, would be less and less as the distance from the northeast and northern border of the basin increased, so that the extent of chemical change would decrease as the distance increased. It is therefore to be expected that in the northeastern corner, where the deltas were formed quickly after a subsidence and beyond which they advanced slowly, as shown by the changing type of rocks, the chemical change should have been almost complete, especially in the eastern Middle and eastern extremity of the Southern field, which occupy that part of the area in which the coal marsh, in almost every instance, appears to have thrust itself first upon the advancing delta.

It is quite possible that when detailed study of the anthracite areas in Arkansas and Russia have been made, the same explanation may be found applicable there also, and that the anthracite will be found near the old shoreline, whence the marsh advanced as new land was formed.

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# EVIDENCES OF THE DERIVATION OF THE KAMES, ESKERS, AND MORAINES OF THE NORTH AMERICAN ICE-SHEET CHIEFLY FROM ITS ENGLACIAL DRIFT

BY WARREN UPHAM

*(Read before the Society August 16, 1893)*

CONTENTS



## INTRODUCTION.

Two widely diverse opinions are held among glacialists in seeking to explain how the ice-sheet transported its drift and left it amassed in its various deposits. One supposes that the drift was carried forward chiefly beneath the ice, being pushed or dragged along in contact with the land; the other, that it was in large part, or perhaps nearly all, englacial during its transportation, being enclosed in the lower part of the slowly moving ice-sheet. According to the latter view, which my observations lead me to accept, the drift after its journey in the ice was thence deposited not only in the knolls, ridges and hills called kames, eskers, moraines, and drumlins, but also in low and smooth or only moderately undulating tracts of till. The opinion first noted regards the ice-sheet

as almost destitute of enclosed drift, excepting very near its base; while the second considers the bottom of the ice as an eroding rasp or plow and its lowest quarter or third as a vehicle and mill in which the greater part of the bowlders, gravel, sand and clay of the drift were borne forward and intermingled.

Several examples of exceptionally massive and conspicuous kames, eskers and moraines, which I have examined and studied in the United States and Manitoba, are described in this paper, special attention being directed to the evidences that they were derived chiefly from englacial drift. Having thus shown that the ice-sheet transported much drift within its mass, reasons are adduced for believing that likewise nearly all of the materials of our smaller accumulations of these kinds, and also the valley drift, were of englacial origin. Further we will inquire to what extent and how the englacial drift appears to have contributed to the subglacial till forming drumlins and the general ground moraine.

Previous literature on this subject supplies the following citations of authors who believe that there was much englacial drift:

J. D. Dana: Transactions Connecticut Academy of Arts and Sciences, vol. ii, 1870, pp. 66-86. American Journal of Science, III, vol. v, pp. 198–211, March, 1873, and numerous papers in vols. x, xii, xxiii, xxiv, xxvi, and xxvii, 1875-1884. Manual of Geology, first edition, 1862, p. 547; second (1874) and third (1880) editions, p. 543.

N. S. Shaler: Proceedings Boston Society of Natural History, vol. xiii, 1870, pp. 196–204. U. S. Geological Survey, Seventh Annual Report, for 1885–'86 (published 1888), pp. 322, 323.

N. H. Winchell: Geological and Natural History Survey of Minnesota, First Annual Report, for 1872, p. 62. Popular Science Monthly, vol. iii, pp. 293, 294, July, 1873.

G. F. Wright: Proceedings Boston Society of Natural History, vol. xix, pp. 47–63, Dec., 1876; vol. xx, pp. 210-220, April, 1879. The Ice Age in North America, 1889.

C. H. Hitchcock: Geology of New Hampshire, vol. iii, 1878, chapter ii, p. 282, etc.

Warren Upham: Proceedings American Association for the Advancement of Science, vol. xxv, for 1876, pp. 216–225. Geology of New Hampshire, vol. iii, pp. 3-19, 176, 285-309. "Inequality of Distribution of the Englacial Drift," Bulletin Geological Society of America, vol. iii, 1892, pp. 134–148. "Criteria of Englacial and Subglacial Drift," American Geologist, vol. viii, pp. 376-385, Dec., 1891. "Conditions of Accumulation of Drumlins," American Geologist, vol. x, pp. 339–362, Dec., 1892. "Englacial Drift," American Geologist, vol. xii, pp. 36–43, July, 1893.

Otto Torell: American Journal of Science, III, vol. xiii, pp. 76–79, Jan., 1877.

N. O. Holst: Paper on the Origin of Eskers, published in Sweden in 1876, reviewed, with notices of Holst's observations of englacial drift in Greenland, by Dr. Josua Lindahl in American Naturalist, vol. xxii, July and Aug., 1888.

References to the alternative opinion, that the englacial drift was of small amount, and that the drift transportation was mainly subglacial, are as follows:

James Geikie: The Great Ice Age, second edition, 1877, pp. 415, 416, etc.

T. C. Chamberlin, U. S. Geological Survey, Third Annual Report, for 1881-'82 (published 1883), p. 297, earliest proposing and defining the term *Englacial or Superglacial Till.* "Boulder Belts distinguished from Boulder Trains—their Origin and Significance," Bulletin, Geographical Society of America, vol. i, 1890, pp. 27-31. "The Nature of the Englacial Drift of the Mississippi Basin," Journal of Geology, vol. i, 1893, pp. 47-60. "The Horizon of Drumlin, Osar and Kame Formation," Journal of Geology, vol. i, pp. 255-267; and editorial remarks, pp. 521-524.

R. D. Salisbury: Geological Survey of New Jersey, Annual Report for 1891, pp. 65-83; ditto for 1892, pp. 38, 39, 50-59. American Geologist, vol. x, p. 219; vol. xi, p. 243.

## Kames forming the terminal Moraine of Long Island eastward from Roslyn.

The outermost moraine southeast of New York and south of New England, explored by the writer fourteen years ago, is a conspicuous series of hills called "the backbone of Long Island," stretching along the entire length of this island, beyond which the same moraine reappears farther east in Block island, Martha's Vineyard, and Nantucket.* Through a distance of more than seventy-five miles on Long island, from Roslyn east to Napeague at the western end of the peninsula of Montauk, this line of hills, though continuous in a narrow and mostly simple series, doubtless accumulated at the margin of the ice-sheet, differs remarkably from any other equally prominent and prolonged portion of any moraine among the many which have been traced and mapped in the northern United States and southern Canada. Elsewhere usually the morainic drift is till, or at least, if it consists partly or sometimes almost wholly of stratified gravel and sand, it yet has frequent portions more or less filled and overspread with bowlders, which indeed are commonly ten to twenty or even fifty times more abundant there than in and upon adjoining lower till areas. For nearly twenty-five miles, from the Narrows east-northeast to Roslyn, this moraine is composed of till, or the unstratified glacial drift, with plentiful bowlders, and rises in irregular undulating hills from 100 to 250 feet above the sea. But from Roslyn to Napeague the accumulation of morainic till, if any exists in the nucleal part of the hill range, is almost completely enveloped and concealed by fluvial deposits. The moraine there is a series of very

*Am. Jour. Sci., third series, vol. xviii, Aug. and Sept., 1879, pp. 81-92, 197-209.

massive, irregular grouped and connected kames, or hills and short ridges of gravel and sand, distinctly stratified, often in oblique layers, and containing water-worn pebbles and cobbles of all sizes up to a foot in diameter, but having few large bowlders or none. Harbor hill, the highest point on Long island, Jane's, Ruland's, and Osborn's hills are of this modified drift; as also is nearly the entire range, both in its lower portions and at its highest summits, through this distance of about eighty miles. Wheatly and Kirby hills, however, are exceptions, being composed of till, while in a few other places, generally of small area, bowlders are found in abundance.

Heights of the most prominent summits in their order from west to east along this part of the moraine are as follows: Harbor hill, half a mile east of Roslyn, 384 feet above the sea; Wheatly hill, three miles farther east, about 380 feet; Spring hill, two miles northeast, and Kirby hill, three miles east from the last, each about 350 feet; Jane's hill, the highest of the West hills, 354 feet; the Dix and Comac hills, about 250 feet; Pine hill and Mount Pleasant, west of Ronkonkoma lake, about 200 feet; the Bald and Selden hills, 200 to 300 feet; Ruland's, the highest of the Coram hills, 340 feet; Homan's hill, north of Yaphank, about 250 feet; Terry's hill, south of Manorville, about 175 feet; Rock and Canada hills, about 200 feet; Spring hill, about 250 feet, and Osborn's or Bald hill, 293 feet, the last two being a few miles southwest from Riverhead; the East hills, and the range onward to Canoe place, 150 to 200 feet; Sugarloaf, the highest of the Shinnecock hills, 140 feet; the Pine hills, 150 to 250 feet, reaching their greatest elevation three miles southwest from Sag Harbor; and Stony hill, a mile northeast from Amagansett, 161 feet.

My exploration and study of this long range of morainic kames leads me to ascribe them confidently to streams formed upon the surface of the ice-sheet by its ablation and by rains, having their beginnings many miles back from the ice-front, gathering much of the englacial drift which had become superglacial, and depositing the coarser part of their load in these hills of gravel and sand at their mouths, where their comparatively steep and rapid descent from the ice was slackened by reaching the open land at its border.

The alternative view supposes that the kame gravel and sand which we find to have been amassed in such vast amount along this part of the ice-front were brought there by subglacial streams coursing across the bed of Long Island sound, ascending thence from 200 to 400 feet in their tunnels beneath the ice, carrying the modified drift upward to their mouths at the ice-border, and accumulating it in these hills 100 to 250 feet above the intermediate hollows. From this moraine a low plain of

finer gravel and sand, brought by the same streams, slowly descends at the rate of ten or twenty feet per mile southward to the shore, and continues onward beneath the sea level. Many broad stream courses, now dry or occupied by insignificant brooks, extend across this plain from the morainic hills to the sea; and in some cases they are traceable below the present sea level, passing across the bottoms of the enclosed bays to the beach-ridge which divides them from the open ocean. It is thus known that when the ice-front stood at its moraine and the streams of its melting formed the kames and ran across this plain, the land here stood somewhat higher above the sea than now.

Which of these views is the true explanation of the origin of the kames, whether they were formed by streams flowing down from the melting surface of the ice-sheet, or flowing upward from its bottom, I am willing to leave to the decision of physicists and of engineers who know the great hydraulic pressure of the head of water under which the supposed subglacial streams must have risen to the tops of these high morainic kames, which often stand as isolated hills with heights of 100 to 250 feet above the lower ground surrounding them on all sides.

## The Pinnacle Hills Esker, Rochester, New York.

Through the southeast edge of the city of Rochester, New York, a very interesting esker, called the Pinnacle hills, extends about four miles in a nearly straight west-southwesterly course. This esker and the adjoining country, with another esker series several miles distant to the southeast, I examined carefully during a few days following the summer meeting of this Society in Rochester last year, and have presented a description of these ridges of drift gravel, with discussion of their origin, in the current volume of the Proceedings of the Rochester Academy of Science.* The Pinnacle hills rise from a nearly flat region to a height which varies from 75 to 200 feet. Their highest point is 229 feet above the University of Rochester, 502 feet above lake Ontario, and 749 feet above the sea. Gravel and sand, irregularly bedded and containing no bowlders, constitute their principal mass, as is usual for the entire accumulations of our eskers and kames; but in some very limited portions the stratified beds of the Pinnacle hills enclose exceedingly abundant bowlders of all sizes up to 8 or 10 feet in diameter, and they are less plentifully but yet frequently found in and upon other considerable parts of the range, including its highest summit. The difficulty of accounting for the transportation of the bowlders to their present places in the stratified, river-deposited esker is increased by the proximity of the rock formation

* Vol. ii, Jan. 9, 1893, pp. 181–200.

from which some of them must have been derived. These are Niagara limestone bowlders, which are a large proportion wherever bowlders are found in this esker; but they can have been transported no more than three or four miles from their parent ledges, since the northern limit of the outcropping belt of the limestone lies within that distance.

For similar reasons as in the case of the Long Island moraine, I conclude that this esker was deposited by a stream descending from the dissolving ice surface, and not by any subglacial river welling upward from an ice-covered tunnel traversing the lowland 200 to 250 feet beneath the crest of the ridge. As a corollary linked with this conclusion, the ascent of the glacial currents which had carried drift into the ice on this area appears to have been sufficient to raise the bowlders within three or four miles from their sources to heights exceeding 200 feet above the land surface. This would be, however, perhaps no more than a gradient of one degree, which gives 92 feet of rise in each mile of advance. In other words, the ratio between the uplift of the bowlders into the ice-sheet and their transportation forward need have been no more than 1:57, instead of the abrupt ascent which at first thought one might suppose to be required.

## DEVIL'S HEART HILL, NORTH DAKOTA.

Several retreatal moraines of the ice-sheet are united in a complex belt, chiefly consisting of knolly and hilly till, which stretches along the southern side of Devil's lake in North Dakota, comprising the Dovre, Fergus Falls, and Leaf Hills moraines, or the seventh, eighth, and ninth in the series of eleven which I have traced in Minnesota, North Dakota, and Manitoba. At an angle in this belt, where it is joined from the south by the Dovre moraine, stands the most prominent hill of all this region, aloof from any high accumulations of the morainic till, and rising as a cone 175 feet above its base, to a height of 290 feet, as barometrically determined by Nicollet, above the lake, or 1,722 feet above the sea level. This hill, known by the translation of its aboriginal designation as the Devil's Heart, is the largest and most remarkable isolated kame that has ever come under my observation. Its slopes are very steep on all sides excepting the south, where the otherwise nearly round topped, conical hill is somewhat drawn out into a narrow, more slowly descending ridge. It consists of gravel and sand, mostly not showing pebbles on the surface larger than one and a half inches in diameter. A few bowlders, however, a score or more in all, are seen on the sides of the hill to its top; and one a foot long (the only one seen at the crest) is embedded in the gravel one rod south of the highest point and less than one foot lower. This

mound I think to have been deposited where a glacial river descended from the convergent slopes of the ice-sheet to the open land contemporaneously with the formation of the Dovre moraine. Its material therefore is regarded as englacial drift which had become superglacial.

It seems very difficult or impossible to entertain the alternative hypothesis, that the stream bringing this gravel and sand and heaping it in this high, lonely hill, 175 feet above the surrounding country, came from a subglacial tunnel which would pass across the bed of the lake a few miles distant on the north and more than 300 feet below the hill crest. Could a stream flowing upward from beneath the ice form a lone, conical mound of so great height and carry bowlders up to its summit?

### Bird's Hill, an Esker near Winnipeg, Manitoba.

Seven miles northeast of Winnipeg, at the station of Bird's Hill on the Canadian Pacific railway, is the esker from which the station was named. This massive ridge of gravel and sand extends about one and a half miles in an east-southeast course and has a height about 50 feet above the very flat expanse of the vast plain of the Red River valley which stretches far away to the west, its altitude here being represented by the railway, 759 feet above the sea. On the northern slope of the esker are strewn rather plentiful bowlders, but none or very few occur on its top and southern slope, and none are imbedded in its mass, which is well revealed by an extensive excavation for railway ballast. This hill, which I have more fully described elsewhere,* seems to me clearly referable to deposition by a river flowing down from the surface of the melting ice-sheet on the north. The bowlders were doubtless dropped or stranded from bergs and floes on the surface of the glacial lake Agassiz, before the border of the ice-sheet had retreated from the vicinity. Indeed, their occurrence chiefly on the northern slope indicates that they were mostly stranded there while ice yet remained beneath this deposit and prevented its entire submergence in the lake. The thickness of underlying ice, when it permitted the bowlders to be stranded only on the northern side of the ridge, must have slightly exceeded 500 feet, since that was the depth of the early highest stage of the ice-dammed lake above the top of Bird's hill. We thus learn that much drift had been enclosed within the ice-sheet at greater altitudes than 500 feet above the very level country on which it rested and from which the drift had been eroded and borne upward into the ice.

Another very noteworthy observation suggests that the volume of the englacial and finally superglacial drift above that height averaged several

*Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv, for 1888–'89, pp. 38–42E.

feet in thickness. Imbedded in the gravel of the ballast excavation I noted a mass of ordinary till, unstratified bowlder-clay inclosing gravel and bowlders in a solid matrix of somewhat sandy clay, wholly bounded by definite but irregular outlines, its dimension vertically being about 10 feet and its length 20 feet. No other mass of till, either of small or large size, was observed in this entire section, which had an extent of three-fourths of a mile and a depth varying from 10 to 30 feet. This till mass probably was derived from the drift that finally overspread the surface of the ice-sheet when the greater part of its thickness was melted, for it seems to have fallen into the channel of the glacial river from the brink of one of its enclosing high ice-walls.

### Retreatal Moraines adjoining Lake Agassiz.

Conspicuous moraines record four halts or stages of slight re-advance of the ice-border, interrupting its general retreat upon the country at each side of the glacial lake Agassiz, which was held by this receding barrier in the basin of the Red river of the North and of lake Winnipeg. These are the Fergus Falls, Leaf Hills, Itasca, and Mesabi moraines, being the most northern four of the series already mapped in Minnesota and the region extending thence west and northwest; but they all belong to the southern third or half of the entire extent of lake Agassiz. When the forest-covered and almost uninhabited country northward shall be fully explored, probably the number of moraines ascertained to have been formed contemporaneously with the existence of this glacial lake will be at least doubled. Each of the four moraines noted comprises portions which rise in hills 150 to 200 feet high; and the Leaf hills, the most prominent morainic accumulations ever seen by me, are scattered upon a width of three to five miles along an extent of fifty miles, and lift their crests 100 to 350 feet above the intervening hollows and the general drift expanse.

Inquiring how these high hills of marginal drift were amassed, we must bring our explanations into accord with a very surprising rapidity of accumulation and brevity of time during which the ice-front was nearly stationary for the formation of each moraine. Comparison of the shore erosion and resulting beach gravel and sand deposits of lake Agassiz with those of lake Michigan shows that the duration of the glacial lake was no longer than a tenth of the postglacial epoch. The entire term of existence of lake Agassiz, therefore, was about a thousand years.* Such a geologically short time witnessed the recession of the ice-sheet from the lake area, nearly 700 miles long from south to north,

* Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, vol. iv, for 1888-'89, pp. 50, 51 E.

with the formation of all its adjacent moraines, for any one of which there would be, in proportion to its size, some ten, twenty, or fifty years. Even the Leaf hills probably required for their accumulation no more than half a century. To bring the morainic drift so rapidly and abundantly to the margin of the ice-sheet, subglacial dragging and pushing seem to me quite inadequate. If this drift, however, was chiefly englacial and at last superglacial, becoming several or many feet thick on the outer part of the melting ice surface, a pause in the recession of the glacial boundary, with a continual forward movement of the ice to its moraine at a rate probably much faster than the motion of the glaciers in the Alps, but slower than of arctic glaciers terminating in the sea, would amass a common moraine in five or ten years, and a few decades of years would suffice to form the Leaf hills. This view looks on the morainic drift as brought down from the adjoining higher part of the ice-sheet, where its currents were strong and rapid because the slope was steep; but if the drift was transported subglacially it must have moved very slowly on account of retardation of the basal ice currents by friction on the land and by the obstruction of the growing moraine, upon which, in the highest hills, the vertical amount of upward pushing would be 100 to 350 feet.

Where the courses of continuation of these moraines traverse the area of lake Agassiz, no hills nor even hillocks are found, but the surface has unusually plentiful bowlders. The drift corresponding to the moraines is spread so evenly that one scarcely observes any addition above the general sheet of till forming adjacent parts of the lake bed; except that one of these belts of smoothly levelled morainic till, a few miles wide, stretches continuously across the Red River valley, rising very slightly above its broad alluvial tract which otherwise is uninterrupted along a distance of 250 miles. If the morainic drift was supplied from the surface of the melting frontal slope of the ice-sheet, it would be washed away and levelled in the lake by the great waves of storms; but if it had been subglacial and thence was pushed out and first uncovered from the retreating ice under the water, much of it would have escaped the levelling action of the lake.

## The foregoing Examples regarded as Types of the general Manner of Transportation and Deposition of the Materials of Kames, Eskers, and Moraines.

During my studies of kames, eskers, and moraines in many districts, exploring new fields each year since 1874, the explanation of their origin chiefly from englacial and finally superglacial drift has seemed to me generally applicable everywhere. Because the validity of this explana-

tion is doubted by some most experienced glacialists, I have subjected it to critical reconsideration, and have thereby gained new confidence that it is true. The examples which have been described and discussed seem representative of all our kames, eskers, and moraines. Small deposits belonging to these classes, not less decisively than the grand instances reviewed, appear by similar features to be likewise of englacial derivation.

The drift on Long island may be thought to have become englacial only by being eroded from the hills and mountains of New England on the north, being carried forward in the portions of the ice-sheet passing their sides and crests; but at Rochester, N. Y., and in the region of lake Agassiz and of Devil's lake in North Dakota, it must have been carried upward into the ice on a nearly flat country. All glacialists readily admit that land ice flowing over a mountainous country must carry more or less of its drift onward enveloped within the ice at great heights; but we have good evidence at Rochester that glacial currents on that nearly level area rose from the bottom of the ice into its mass so rapidly as to carry bowlders up more than 200 feet within a few miles, and at Bird's hill we see that there was much englacial drift borne along in the ice-sheet upon that vast flat region at greater altitudes than 500 feet above the ground. Not only from these flat areas, but also from lowlands among hills and mountains, I think that much drift was eroded and carried upward into the lower quarter or third part of the ice-sheet, being most abundant near the ground and gradually diminishing upward. The steady accession to the mass of the ice-sheet over any place by onflow from its thicker central part and especially by the accumulating snowfall doubtless forbade the drift of the upwardly moving basal current from being carried far into the ice in comparison with its total thickness.

Bowlders and other drift becoming incorporated in the higher portion of the zone reached by the currents flowing upward would be carried forward far at that height in some regions, as from the Huronian and Laurentian areas north of lake Huron to the bowlder belts in Illinois, Indiana, and Ohio, described by Chamberlin, without intermixture with other englacial drift brought into the ice by less powerful currents on all the intervening extent, which in the case mentioned is about five hundred miles. The englacial transportation proved for these bowlders seems to me to imply that much drift of less distant origin was carried in the ice at lower altitudes, and that the portion of the englacial drift within a few hundred or probably a thousand feet above the land, where the ice-sheet was a half mile to one mile thick, must have become well intermingled.

In the morainic till, if I rightly understand its derivation, we have accumulations predominently supplied, especially on their surface, from the upper part of the englacial drift. Its bowlders have travelled without attrition and are deposited usually in large numbers. A narrow belt aggregates as many unworn rock fragments of large and small size as belong in the veneer of englacial material falling from the departing ice upon the surface of a very wide adjoining tract.

When the returning warm climate at the end of the Glacial period melted away the ice, its ablation exposed the formerly englacial drift upon its surface, as the border of the Malaspina glacier or ice-sheet in Alaska is found by Russell to be covered thickly by drift which supports a growing forest. The recession of the Pleistocene ice-sheet, however, during the time including the formation of its complex series of moraines in the northern United States and southern Canada, although often interrupted and demonstrably attended by many irregularities and inequalities in the rate of retreat and in the extent and duration of the oscillations of its frequent pauses and re-advances when the moraines were formed, was yet probably so rapid that no vegetation gained a foothold on its drift-covered frontal slope. Rains falling and rills and larger streams flowing on the freshly revealed drift of the melting ice surface gathered portions of it and deposited them in ice-walled channels and at the mouths of the glacial rivers as eskers and kames, and on the adjoining land as plains of gravel and sand, and beyond these as beds of fine silt, loess, and clay, laid down in lakes or more commonly in very gentle river floods spreading across wide valleys. Besides the moraines, kames, and eskers, the valley drift also, in its great volume and diverse phases, thus seems to have been chiefly supplied from drift that was enveloped in the ice-sheet at the time of its final melting.

### Relations of the englacial Drift to subglacial Till.

The superficial portion of the general sheet of till which appears to have fallen from the ice-sheet at the time of its departure is commonly no more than a few feet thick; but it is very unequally distributed, varying from almost nothing to depths of forty feet on some tracts to which glacial currents carried this englacial drift in exceptional amount. The lower and usually much greater part of the till was deposited beneath the ice-sheet, but for almost the entire drift-bearing area, excepting only near its boundaries, I think that this deposition took place mainly, or at least in large measure, during the time of the recession of the ice-sheet. According to this view, the drift which became then massed in the ground moraine had up to that time been englacial, being gradually

eroded from the land and slowly borne forward in the very sluggishly moving basal portion of the ice.

Nearly all the rock surface of glaciated countries first suffered much erosion by the ice-sheet, before the deposition of its drift. This implies that all of the drift on these great areas has been at some time englacial, since the base of the moving ice studded with its enclosed drift was the agent abrading the rock and producing its striæ. Observations of widely different glacial striation on adjoining parts of the same rock exposure, the two sets of striæ being on surfaces of slightly different inclination which join each other with a bevelled edge or angle, convince me that a very definite plane divided the bottom of the ice-sheet with its enclosed drift bowlders, pebbles, and sand grains, which acted as graving tools, from underlying stationary drift accumulations, not less than from the immovable bed-rock. There was, at least in the places of these crucial observations, no pushing or dragging forward of the drift beneath the ice. Several of these localities of adjacent differently striated bevelled rock surfaces I have noted in southwestern Minnesota, and others in Somerville, Massachusetts.* In all these places the contrasted directions of glaciation are apparently referable to deflections of a continuous ice-current, rather than to any withdrawal and subsequent new advance of the ice-sheet. During some considerable interval between the times of different courses of the glacial current, a very thin layer of stationary drift covering a part of the rock surface protected it from striation while the later ice erosion engraved its striæ on the closely contiguous part of the same ledge. Here, and I think likewise generally, the only transportation of drift took place within the moving ice-sheet, not by any sliding or rolling under it. Where all the underlying rock is glacially worn and striated, we must therefore conclude that all the drift earlier or later was carried into the ice.

How the continental ice-sheet could thus erode all its rock-bed, excepting areas near the limits of its farthest extension, and yet finally leave the same rock-bed, upon many large tracts, completely and deeply enveloped by the subglacial till, I have attempted to show in the accompanying idealized section (figure 1) of a portion of this ice-sheet in the Mississippi basin. On the southern part of the drift in that region no continuous moraines were accumulated, and I attribute their absence principally to the attenuated condition of the ice there and its lack of a steep border. During the glacial retreat, wherever the vicissitudes of the wavering climate caused the chiefly waning ice-border to remain

*Geology of Minn., vol. i, 1884, pp. 504–5 and 549–50. Proc. Boston Soc. Nat. Hist., vol. xxvi, 1893, pp. 33–42. Compare with Professor Chamberlin's memoir, "The Rock-Scorings of the great Ice Invasions," U. S. Geol. Survey, Seventh An. Rep., for 1885–'86, pp. 147–248, especially pp. 175, 176, 200–207.

nearly stationary during several years the vigorous outflow of the ice to its steep frontal slope brought much drift which had been englacial and on account of the ablation became superglacial, dumping it, as we may say, in the irregular moraine embankments. As these marginal accumulations of drift record the position of the terminal line of the ice-sheet when they were formed, the name terminal moraines has been usually applied to them, but they may also very properly be called retreatal or recessional moraines. Along all the pathway of retreat of the ice, that is, over all the land which it had covered, as in front of the places of the moraines, beneath the tracts where they were soon to be accumulated, and farther northward, I think the deposition of the subglacial till to have been somewhat rapidly in progress upon a belt probably 20 to 50 miles in width next backward from the receding ice boundary, this belt being in gradual retreat from south to north.

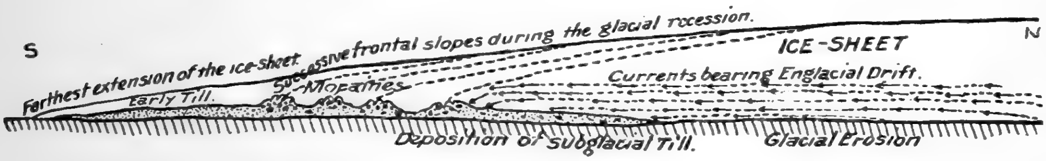


**Figure 1.**—*Section of the Ice-sheet in the Mississippi Basin along a Distance of 300 Miles north from its most southern Boundary.*

The manner in which the ice gathered drift into its basal portion from any plain tract seems to me explainable by a consideration of the currents of outflow toward its border. Even in the central area of the ice-sheet the currents of its upper and lower portions probably moved outward with quite unequal rates, the upper movement being faster than at the base. This contrast was increased, however, upon a belt extending many miles back from the margin, where the slope of the ice surface had more descent, for there the upper currents of the ice, unsupported on the outer side, would move very much faster than its lower currents which were impeded by friction on the land. Within this belt, accordingly, there would be a strong tendency of the ice to flow outward with somewhat curved currents (shown by dotted lines with arrows in the figure), tending first to carry the outwardly moving drift gradually upward into the ice-sheet, and later to bear it downward and deposit it partly beneath the edge of the ice as subglacial till, and partly along the ice boundary as moraines when any halt permitted such accumulation.

A very good analogy with the slowly rising currents which I believe to have existed in many portions of the base of the ice-sheet is afforded by the edges of alpine glaciers, where the crevasses extending diagonally upstream into the glacier testify that the movement of its friction-hindered border is from the side of the valley into the ice. But the arched

surface of the glacier and the great supply of its central current prevent the drift so worn off and borne away from being carried into the axial portion of the ice stream. Similarly the currents sweeping drift from the land into the ice-sheet were probably limited, as before remarked, to the lower fourth or third of its whole mass.

The abundant englacial drift that was being transported very slowly at heights not far above the ground appears, during the glacial recession, to have been at last carried downward beneath the outer part of the ice-sheet and amassed in the usually flat or moderately undulating ground moraine. Under certain peculiar conditions, due to climatic influences, I suppose that great quantities of the ice-held drift, having once become superglacial, were again covered by onflowing ice and heaped by its convergent descending currents in the high oval hills of till called drumlins. Rarely some of these hills, as Third and Fourth cliffs in Scituate, Massachusetts, and the Capitol, University, and Observatory hills in Madison, Wisconsin, contain a nucleus of subglacial stratified sand and gravel, which is enveloped by the subglacial till, with so much of the englacial drift on the surface as still remained in the ice until its melting from these areas.

When the North American ice-sheet attained its greatest extent, erosion probably was in progress on all the ice-covered country, excepting near its limits, being most rapid within some such distances as from 100 miles to 200 or 300 miles back from the boundary. Deposition prevailed, we may infer, on a somewhat broader peripheral belt than during the ensuing time of disappearance of the ice-sheet, which was attended by the recession of this belt, estimated to have been then 20 to 50 miles wide, across all the previously eroded country. The englacial drift supplied by the wide and long continued erosion was then laid down, according to the view here presented, in great part and apparently more than half of it all, as the ground moraine of subglacial till, and the remainder formed the retreatal moraines, kames, and eskers, and the valley drift in its varieties of gravel, sand, clay, and loess.

## *DISCUSSION.*

T. C. Chamberlin: It is an undeniable fact that kames, eskers and moraines contain a very considerable percentage of local material. Sometimes by far the larger portion of it is derived from formations not far distant. If these kames, eskers and moraines were formed from englacial material which became, by ablation, superglacial material, it must have been through some process of upward movement within the ice, as urged by the author of the paper. If there were such upward movement, modern glaciers should show upon their surfaces and terminal slopes material of like nature. This they do not seem to present, as a rule. There may, of course, be exceptions. I have examined very carefully the material on the surface and slopes of a considerable number of glaciers and found it invariably of sharp, angular, unworn forms. I would call attention particularly to the englacial material that comes to the surface on the terminal slope of the Rhone glacier. This I found to be altogether angular and entirely without any evidence that it had been at the bottom of the glacier or had suffered the rounding which the material of kames, eskers and moraines present. The basal material of the same glacier was, however, well rounded, and the moraines just below contained large quantities of this rounded material.

Frank Leverett: It would seem as though a practically continuous sheet of drift several feet in thickness should have been deposited during the retreat of the ice-sheet if the amount of englacial drift were as great as advocated by Mr. Upham, and I would call attention to the fact that in districts where there has been but a single ice invasion, as in southern Illinois and in portions of Illinois and Wisconsin bordering the driftless area, there are large districts across which the ice-sheet retreated without leaving a sheet of drift—the former existence of the ice-sheet there being known only by the presence of scattering bowlders and occasional patches of till of slight depth.

H. F. Reid: Mr. Upham thinks that in a glacier occupying a canal-shaped valley there is a component of the motion at right angles to the shore in order to open the lateral crevasses. This is not necessary, for if the motion is strictly parallel to the sides and is more rapid as the center is approached, oblique marginal crevasses will be formed. In fact the direction of motion cannot be inferred from the direction of a crevasse without also considering the relation of the crevasse to the glacier itself—that is, without knowing whether the crevasse is lateral, transverse or longitudinal.

With regard to the upward ice-currents in the glacier, I cannot see how they could be produced, or if produced how they could be preserved. Either a hole would be left under the ice, into which the ice would sink by its own weight, or there would be left a mass of stagnant ice over which the rest of the glacier would move. It does not appear why this mass of ice should remain at rest when the ice immediately behind it, in front of it, and above it moves.

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# THE SUCCESSION OF PLEISTOCENE FORMATIONS IN THE MISSISSIPPI AND NELSON RIVER BASINS

BY WARREN UPHAM

*(Read before the Society August 16, 1893)*

CONTENTS



## INTRODUCTION.

During fourteen years, since June 9, 1879, my field observations and constant studies, successively for the geological surveys of Minnesota and of the United States, have been directed chiefly to the glacial and modified drift of Minnesota, northern, central and northwestern Iowa, the eastern borders of South Dakota, nearly all of North Dakota, excepting the country southwest of the Missouri river, and the large prairie portion of Manitoba. These areas comprise the upper part of the Mississippi basin, the whole district drained by the Red river of the North above the city of Winnipeg, and the lower part of the basin of its large western tributary, the Assiniboine, the two last named streams being portions of the Nelson river system, sending their waters through lake Winnipeg and the Nelson to Hudson bay.

In mapping the marginal moraines of the Minnesota and Iowa lobe of the ice-sheet, the first and outermost, named the Altamont moraine, was found to extend in a U-shaped loop south to Des Moines. Ten later

approximately parallel retreatal moraines, marking stages of halt or slight reädvance, interrupting the general retreat of the ice-sheet, have been mapped through Minnesota and North Dakota, and partially in southwestern Manitoba. These are the northwestward extension of the moraines mapped in Wisconsin, Illinois, Indiana, and Ohio by Chamberlin and Leverett; and the outer two or more of their representatives farther east in New York, northeastern Pennsylvania, northern New Jersey, and the New England states were mapped ten to fifteen years ago by Chamberlin, Lewis, Wright, Cook and Smock, and the present writer. Within the last few years additional moraines farther north in Massachusetts, New Hampshire, and Vermont have been traced by Tarr and Hitchcock. No other problem of our glacial drift can be more interesting than the correlation of these moraines across the continent, or at least from the Atlantic coast to the northwestern plains bordering the Cordilleran mountain belt, since thereby the successive boundaries of the whole front of the ice-sheet during many stages of its recession are becoming known.

My attention, however, has been drawn more to the history of the glacial retreat upon the central south to north belt of the Mississippi and Nelson river basins, since this belt includes the area of the glacial lake Agassiz, which was held in the basin of the Red river of the North and of lake Winnipeg by the barrier of the departing ice-sheet. Through my study of this ancient lake I have been led to careful consideration of the retreat of the ice from its outer moraines northward past all the numerous and partly very complex marginal belts of knolly and hilly drift accumulated during pauses of its recession contemporaneous with lake Agassiz, until this vast body of water obtained avenues of northeastward outflow and finally was drained into Hudson bay, excepting its shallow present descendants, lakes Winnipeg, Manitoba, and others, left in the depressions of its bed. This portion of the departure of the ice I find to have been surprisingly rapid. Comparison of the shore erosion and accumulation of beach gravel and sand by the waves of lake Agassiz with those of lake Michigan indicates for the relative durations of these lakes a ratio as 1:10 or 1:20. Lake Michigan has existed and worn away its shores and built up its beaches and dunes during the postglacial epoch, which appears, from various independent but approximately accordant estimates by N. H. Winchell, Gilbert, Andrews, and others, to have been some 6,000 to 10,000 years. The existence of lake Agassiz, therefore, with the accumulation of its several associated large moraines, occupied no more than 1,000 years.

Is this conclusion consistent with all the otherwise known records and inferred conditions of the Ice age upon this central belt of our conti-

nent? This question has led me to review in the present essay the series of formations in the Mississippi and Nelson river basins which belong to the times immediately preceding, during, and following the Glacial period, especially considering the changes in the altitude and slopes of the land and the probable measures of time demanded by the processes of drift transportation and deposition, by subsequent weathering with soil formation, and by stream erosion. To take occasionally such a view of the whole era and extended area to which one's limited studies appertain seems to me the duty of every working geologist, that his interpretations of observations in his own field may be guarded from error, and that perchance his neighbor's field of exploration may be better understood.

## The Lafayette Formation and the Saskatchewan Gravels.

The broad lower part of the Mississippi valley, from the southern boundary of the glacial drift to Louisiana, contains a very extensive deposit of sand and gravel, designated formerly from its prevailing ferruginous color as the Orange sand, later called by McGee the Appomattox formation in its development on the coastal plain of the Atlantic and Gulf states, but recently named the Lafayette formation from Lafayette county in northern Mississippi, where it was earliest discriminated by Professor E. W. Hilgard in 1855 and 1856. This formation was spread across the valley plain 50 to 150 miles or more in width along an extent of 600 miles from the mouths of the Missouri and Ohio rivers to the gulf of Mexico, during the closing stage of the Tertiary era and the beginning of the Quaternary, to each of which it has been assigned. McGee,* Chamberlin,† and Salisbury ‡ hold that it is probably referable to the Pliocene period; while Spencer,§ Hilgard,|| and others, as it seems to me preferably, consider it as the earliest of our Pleistocene formations. Its northern continuation beneath the glacial drift is recognized by Salisbury ¶ in western Illinois to a distance of a hundred miles northward from the Missouri river and boundary of the drift, and gravels believed by him to be probably of the same formation occur in the Wisconsin and Minnesota driftless area, while northeastward he has

* Am. Jour. Sci., third series, vol. xxxv, Feb., April, May, and June, 1888; vol. xl, July, 1890. U. S. Geol. Survey, Twelfth An. Rep., for 1890–'91, pp. 347–521, with 10 plates, and 45 figures in the text.

† Bulletin, G. S. A., vol. i, 1890, pp. 469–480. Am. Jour. Sci., third series, vol. xli, May, 1891.

‡ Article last cited. Geol. Survey of Arkansas, An. Rep. for 1889 (published 1891), vol. ii, "The Geology of Crowley's Ridge," pp. 224–248.

§ Geol. Survey of Georgia, First An. Rep. for 1890–'91, p. 62.

|| Am. Jour. Sci., second series, vol. xlii, May, 1866; vol. xlvii, Jan., 1869; vol. xlviii, Nov., 1869; third series, vol. ii, Dec., 1871; vol. xliii, May, 1892. Am. Geologist, vol. viii, Aug., 1891, pp. 129–131.

¶ Bulletin, G. S. A., vol. iii, 1892, pp. 183–186.

observed the Lafayette gravels in the Ohio valley in southern Indiana about 150 miles from the Mississippi. McGee states that the Lafayette beds attain their maximum thickness, which is 200 feet or more, in the region about the mouth of the Mississippi, and that they vary thence to a thin veneer, the thickness being proportional directly with the volume of neighboring rivers and inversely with the extension inland.

Previous to the maximum advance of the ice-sheet, the Mississippi river and all its large tributaries eroded broad and deep valleys through the Lafayette formation and underlying strata, cutting at New Orleans to a depth of at least 760 feet below the present sea level. Along the central valley, from Cairo to the Gulf, this erosion averages probably 200 feet in depth upon a belt 500 miles long, with a width of 50 to 100 miles, excepting isolated plateau remnants of the Lafayette and older beds, of which the largest are Crowley's and Bloomfield ridges, in Arkansas and Missouri. The land during the valley erosion was certainly 760 feet higher than now, but this I think to be only a small fraction of its uplift. From the transportation of northern Archean pebbles and cobbles of crystalline rocks to the Lafayette beds of the lower Mississippi and of Petite Anse island, on the Gulf shore, in the direct line of the axis of the Mississippi valley, Hilgard believes that during the deposition of these beds the valley had a greater descent and stronger currents of its river floods. He suggests that the increased altitude of the interior of the continent needed to give these formerly more powerful currents may have been 4,000 to 5,000 feet, being sufficient, probably, to bring the cold climate and ice accumulation of the Glacial period.

Marine submergence of the low coastal and Mississippi valley areas occupied by the Lafayette formation is supposed by McGee and Spencer to have been requisite for the deposition of its sand and gravel beds, but they see that immediately afterward the land was much higher than now to permit the extensive and deep river erosion of that time. A simpler view of the epeirogenic movements, closing the Tertiary era and inaugurating the Quaternary, seems to me to be found in ascribing these beds to deposition by flooded rivers descending from the Appalachian Mountain region and from the Mississippi basin, spreading gravel, sand, and loam over the coastal plain and along the great valley during the early part of a time of continental elevation. The land had lain during the long Tertiary periods at lower altitudes, and its surface was largely enveloped by residual clays and by alluvial sand and gravel. With the elevation of the continent, increased rainfall and snowfall and resulting river floods swept away these superficial materials from the higher lands and spread them on the coastal plain and along the Mississippi valley,

where the streams expanded over broad areas with shallow and slackened currents. As the elevation increased, however, the rivers would attain steeper slopes and finally erode much of the deposits which they had previously made. During the culmination of the uplift, producing the northern ice-sheet, Chesapeake and Delaware bays were excavated and erosion was in progress at a far more rapid rate than with the present low altitude of this region.

According to this view we may compare the Lafayette formation with the Indo-Gangetic alluvial plain, which stretches along the south side of the Himalayas from the Indus to the Ganges, covering about 300,000 square miles and forming the richest and most populous portion of India. This plain rises from the sea level to an elevation exceeding 900 feet. Its prevailing formation is fine silt or clay, more or less sandy, with gravel near the borders of the plain. The central portions have a thickness of at least 400 to 700 feet, as determined by borings which do not at these depths reach the bottom of the alluvium; and this entire deposit, according to Medlicott and Blanford, is of Quaternary age and of fresh-water origin, having been laid down by the flood stages of the rivers that descend from the very rainy southern slopes of the Himalayan range.*

In the Nelson river basin a gravel and sand formation which appears to be the equivalent of the Lafayette, both in its relationship to the glacial drift and in the conditions of its deposition, is found by Mr R. G. McConnell to have a wide distribution upon the portion of the northwestern plains drained by the South Saskatchewan river and its tributaries. It also is known to extend to branches of the Missouri and of the North Saskatchewan. Mr McConnell writes:

> Under the general name of the South Saskatchewan gravels are included the pebble conglomerates and incoherent gravels and silty beds which are found, as valley or lake deposits, in different parts of the district, and which, although destitute of organic remains so far as examined, are known by their relative position to be intermediate in age between the Miocene and the Quaternary, and to belong mostly to the period immediately preceding the latter. They are, however, not all contemporaneous, and in one or two places afford evidence by the admixture of Laurentian and quartzite pebbles toward the top of a gradual blending with the lowest glacial beds.†

Again, in the valley of the Mackenzie river from Great Slave lake to its delta this formation, according to the following description by the same geologist, underlies the drift and was mostly deposited immediately

*Manual of the Geology of India, 1879, part i, pp. 391–421. Quart. Jour. Geol. Soc., London, vol. xix, 1863, pp. 321–354. Compare Am. Jour. Sci., third series, vol. xli, Jan., 1891, p. 48.

†Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, vol. i, for 1885, p. 70 C.

before the Ice age, but in part was contemporaneous with the earliest stages of the Pleistocene glaciation:

The bowlder-clay throughout the greater part of the valley is overlain by heavy deposits of stratified sands, clays and gravels, probably lacustral in their origin, and is underlain by a gravel terrane somewhat similar to and occupying the same relative position as the Saskatchewan gravels of the plains of Alberta and Assiniboia, but differing in containing a much greater proportion of Laurentian pebbles. These beds have a thickness in some cases of fully 150 feet, and contain well-rounded pebbles, ranging in size up to eight or ten inches in diameter. They are intimately connected with the bowlder-clay, and in one place were observed to alternate with it, and they seem to show that the bowlder-clay period in this region was preceded as well as followed by what may be termed a lacustrine epoch, during which the surface depressions were filled with extensive lakes.*

The manner of deposition of the preglacial beds described here and of those in the Saskatchewan region and in the Mississippi valley seems to me most probably to have been in each case by river floods, rather than in the still waters of lakes or of the sea. In the Saskatchewan region they lie 2,000 to 2,500 feet or more above the ocean, and in none of the districts noted have any shorelines, marine fossils, or other proofs of the presence of the sea been discovered.

## Glacial Drift and marginal Moraines.

The till or bowlder-clay extends either continuously or in patches to the extreme limits reached by the ice-sheet in its maximum advance; but generally on the outer portion of the drift-bearing area glacial planation and striation of the bed-rocks is absent or rare. Upon the greater part of the area of the earlier drift, outside the prominent marginal moraines, a thin remnant of the preglacial residuary clay and decaying rock is left beneath the till, whose material was derived mostly not from the area over which it is spread, but from districts farther north. A broad peripheral belt of the ice-covered country was thus characterized by the deposition of drift, which was supplied from inner portions of this area where the predominant action of the ice-sheet was erosion.

At least twice the continental glacier advanced upon the region of early drift in the Mississippi basin, depositing its till first on the mostly or partly uneroded preglacial surface, and in its second advance similarly sparing large tracts of a forest bed, whose trees and peat swamps had grown during the time between these ice incursions. Russell's observations of the Malaspina glacier show that large trees may flourish close

*Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, vol. iv, for 1888–'89, p. 26 D.

to the boundary and even upon the thinned waning margin of the ice, so that any reädvance may enclose the overwhelmed forest between deposits of till. Indeed, it appears probable that there were several different stages of halt and reädvance of the ice-sheet during its general retreat from this area outside the moraines, and that the buried forest surfaces do not belong wholly to one but to several fluctuations of the ice-front.

When the glacial melting had removed the comparatively thin outer belt of the ice-sheet in the region of the upper Mississippi, its thicker central portions, terminating with steeper gradients, flowed outward to its chiefly restricted limits with far more powerful currents than those which had deposited the smooth expanse of the early drift. This increased vigor of the later ice action is shown by the almost universally worn and striated surfaces of the underlying rock, by the accumulation of large and continuous marginal moraines, and by the irregular surface of the drift inside the roughly hilly morainic belts, with swells, ridges, and intervening hollows which hold many lakes and lakelets.

Eleven retreatal moraines, marking stages of pause or slight forward movement of the mostly retreating ice-margin, are determined in central and northern Iowa and western Minnesota. The first or Altamont moraine was accumulated when the extremity of the Minnesota and Iowa ice-lobe reached to Des Moines; when the second or Gary moraine was formed, it terminated on the south at Mineral ridge, in Boone county, Iowa; at the time of the third or Antelope moraine, it had farther retreated to Forest City and Pilot mound in Hancock county, Iowa; the fourth or Kiester moraine was formed when the southern extremity of the ice-lobe had receded across the south line of Minnesota and halted a few miles from it in Freeborn and Faribault counties; and the fifth or Elysian moraine, crossing southern Le Sueur county, Minnesota, marks the next halting-place of the ice in its recession northward. At the time of formation of this fifth moraine the south end of the ice-lobe had been melted back 180 miles from its farthest extent when the moraines began to be amassed, and its southwest side had retired 30 to 50 miles from the crest of the Coteau des Prairies in southwestern Minnesota and the northeast part of South Dakota; but while these great changes in the area of the ice-lobe were taking place its eastern boundary for 30 miles southward from Saint Paul had fluctuated only slightly, so that a broad compound morainic belt there represents the five moraines which were formed on the south and west. Six later belts of marginal hilly drift, named from localities of their typical development in Minnesota, are in succession from south to north the Waconia, Dovre, Fergus Falls,

Leaf Hills, Itasca, and Mesabi moraines.* Beyond these, in the extreme northern part of Minnesota, in Manitoba and onward, probably as many more stages of the glacial retreat will be recognized whenever that wooded and uninhabited country shall be fully explored.

### Loess and other Modified Drift Deposits.

Much of the grist of drift produced by the ice-sheet was washed away by the streams of its melting and of attendant rains, being deposited in the ice-walled channels of the glacial rivers as eskers, at their mouths as kames and kame-like plateaus, and along the valleys down which the streams flowed on their way to the sea as stratified gravel, sand, clay, and the fine silt called loess. All these genetically related formations, supplied directly from the ice-sheet, especially during its final recession, but modified by currents of water, being thus transported various distances, assorted in coarser and finer deposits, and laid down in stratified beds, are collectively classed as modified drift, in distinction from the unmodified glacial drift or till. If we consider the extensive deposits of the loess and other finer and coarser beds of modified drift which were borne beyond the boundary of the farthest ice advance and their continuation northward upon the till along all the large waterways and on many higher tracts of the glaciated area, it seems hardly too large an estimate to assign a quarter or third part of all the glacial grist to this class of drift modified by stream transportation and deposition. As noted in my preceding paper, I believe that the streams in gathering this drift from the ice-sheet flowed upon its melting surface, and that the modified drift was nearly all derived from material that had been englacial and became superglacial when the ice was melting away.

In the loess of the Missouri and Mississippi valleys, a silt so fine that the waters depositing it appear to have been very slowly flowing, broad, but mostly shallow, river floods from the summer melting of the continental ice-sheet, we have a formation which proves that at the time of maximum ice advance and during the early stages of its recession this great river basin had somewhat less southward descent than now, probably with a lower altitude, yet not sinking to the sea level, and that its floods spread over all the lowlands of the valley plain between its eroded bluffs capped by the Lafayette gravels. During the cooler portions of each year, however, the streams were restricted to comparatively narrow channels; and land shells lived, and probably grass and other vegetation grew, on the bared flood-plain.

* Descriptions of these moraines are in the Final Reports of the Geol. and Nat. Hist. Survey of Minnesota, vol. i, 1884; vol. ii, 1888; and vol. iv, describing northern Minnesota, yet to be published.

Laterally and downward the loess in some places grades into the Port Hudson clays, which are continuous along the bottom of the Mississippi valley from the mouth of the Ohio to the Gulf, having a thickness of more than 600 feet at New Orleans. Near their base both the loess and Port Hudson beds, which are classed together by McGee as equivalent with the Columbia formation of the Atlantic coastal plain, often enclose sandy and gravelly layers, and they very commonly appear to be conformable along the great river, as observed by Hilgard, with the underlying beds of the Lafayette formation. Glacially ground rock flour is the chief or sole ingredient of the Mississippi loess, and it constitutes a part of the Port Hudson clays, while their greater part, however, consists of the very fine silt of this river and its tributaries during a time of depression of the land which followed its elevation and the attendant erosion of the Lafayette sand and gravel and of the Tertiary strata beneath. The coarse basal beds in the Port Hudson and loess or Columbia formation imply at its beginning a close relationship with the conditions of deposition of the Lafayette, and they both seem referable to the same great epeirogenic uplift. During the early part of this time of elevation, before the rivers obtained too steep gradients, I think that the Lafayette formation was deposited; and later, while the depression from this elevation was bringing the continent once more down to approximately its present level, as soon as the streams again flowed with such slopes as to allow them to lay down sediments, they formed the Port Hudson, loess, and Columbia deposits.

Successively as the ice-sheet retreated, all the areas which it had covered, first at the south, then intermediate, and latest at the north, were overspread with modified drift along the avenues of drainage. Besides its deposition in the principal valleys, the glacial rivers flowing down from the melting ice-sheet accumulated eskers, kames and gravel and sand plains where now no streams exist. Among these records of the drainage of the wasting ice-sheet, none perhaps are more remarkable than the eskers of loess in northeastern Iowa, which McGee describes under the aboriginal name paha. He also finds in that district, as I had similarly observed in the northwestern part of the same state, that the margin of the ice as a high barrier formed a boundary of the loess when it was being deposited. The west side of the Minnesota and Iowa ice-lobe was forming the Altamont moraine contemporaneous with adjacent river floods spreading loess across the Missouri valley, and I believe that the loess deposition was mainly continuous, accompanying the gradual and widely extended but wavering departure of the ice-sheet from its farthest boundary to this outermost of the conspicuous morainic belts.

## Lake Agassiz and its Deltas.

From the most southern part of the Nelson river basin, near the middle of the west side of Minnesota, the glacial lake Agassiz extended northward across the entire width of this basin, a distance of about 700 miles; for the waning ice-sheet forming its northern boundary had doubtless receded to the watershed dividing the Nelson and Churchill rivers north of lake Winnipeg before the latest stage of lake Agassiz was finally permitted to outflow along the present course of the Nelson river to Hudson bay. This glacial lake, growing from south to north as the barrier of the continental glacier receded, attained an area of not less than 110,000 square miles, exceeding the combined areas of the great lakes outflowing by the Saint Lawrence; and its depth above lake Winnipeg was about 600 feet. As noted in the introduction of this paper, the retreat of the ice-sheet from this basin appears to have occupied no longer time than 1,000 years; but four large moraines are found to have been formed at stages in the glacial recession contemporaneous with the extension of lake Agassiz from its mouth and southern end north along only a third part of its length. The marginal morainic drift is thus shown to have been accumulated with a surprising rapidity, which seems to have been possible only by its derivation chiefly from englacial and superglacial drift.

Six extensive deltas of lake Agassiz are found in the southern, prairie portion of the ancient lake area, which has been fully explored, with exact mapping of its beaches and deltas, and with determinations of their heights by leveling.* Each of these deltas consists largely of modified drift supplied from the melting ice-sheet during its retreat past the tracts which they occupy; and one of them, brought wholly by a glacial river, lies where the lake area now receives no important inflowing stream. They all belong to the time of the upper Herman beach of the lake, the earliest and highest in a series of about thirty well defined beaches recording successive levels of the lake due to erosion of its outlet, to changes of outlets, and to differential uplifting of the lake basin so that single beaches at its southern end are represented by two, three, or several, in their continuation northward.

## Preglacial epeirogenic Elevation.

Reviewing these Pleistocene formations of the great central river basins of the United States and Canada, I agree with Professor Hilgard in his interpretation of the Lafayette gravel and sand beds as river deposits

*Geol. and Nat. Hist. Survey of Minnesota, Eighth An. Rep., for 1879, pp. 84–87; Eleventh An. Rep., for 1882, pp. 137–153, with map; and Final Report, vols. i and ii. U. S. Geol. Survey, Bulletin no. 39, pp. 84, with map. Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, vol. iv, for 1888-'89, part E, pp. 156, with two maps, and sections.

formed during a preglacial time of high epeirogenic uplift of the northern part of this continent, whose culmination was attended by the accumution of the ice-sheet. On the high plains in the Saskatchewan part of the Nelson basin similar beds underlie the glacial drift and are intimately associated with its lower portion. In the Mackenzie valley stratified gravel and sand likewise preceded the drift and their upper part was interbedded with deposits of till. All these preglacial beds seem to me more closely related to the Glacial period and the conditions producing the ice-sheets than to the preceding very long Tertiary era, and for the same reasons which have been well stated by Hilgard and Spencer, namely, their dependence alike on the epeirogenic elevation. With the Ice age we should unite the probably much longer preglacial time of gradual uplift of the continent, and the postglacial or recent period in which we live, to form together the three successive parts of the Quaternary era.

How long the early part comprising the epeirogenic uplift, represented by the deposition and erosion of the Lafayette formation, may have been, we can only vaguely or perhaps approximately estimate. During the beginning of the uplift its effect would be probably to increase the transportation and deposition of gravel and sand by the rivers many times beyond their present action. The rate of average land erosion now prevailing throughout the drainage area of the Mississippi is supposed by McGee to be competent to supply in about 120,000 years a volume of river gravel, sand, and silt equal to the original Lafayette formation in the Mississippi valley. With the greater altitude and increasing slopes of the land during the deposition of the Lafayette beds it may have required a third or a sixth of the time here mentioned, that is, some 40,000 or 20,000 years. As the elevation continued, however, rapid fluvial erosion of those deposits and of the underlying strata ensued, which was extended over so long and broad an area of the lower Mississippi valley, and to such depth, that, even with the high continental elevation of 2,000 to 3,000 feet known from submerged valleys off both the Atlantic and Pacific coasts, it must have required a long period. Perhaps it may be reasonably estimated twice as long as the time of the deposition, or somewhere between 40,000 and 80,000 years. Meanwhile the northern ice-sheet was accumulated, doubtless fluctuating much during its time of gradual growth and advance as afterward during its decline.

## Depression of the Land previous to the maximum Stage of the Glaciation.

The loess, deposited by very gentle currents of broad river floods in the Missouri and Mississippi valleys, attending the maximum extension

of the ice-sheet and accompanying its departure up to the time of formation of the great marginal moraines, testifies that previous to the farthest glacial advance the land sank to its present altitude, and probably somewhat lower on the area of the early drift, but not to the sea level. The vast weight of the continental glacier seems to have been the chief or only cause of this subsidence, as was first pointed out by Jamieson for the similar depression of the British Isles and Scandinavia at the time of final melting of the European ice-sheet. The explanation of this continuance of the ice accumulation and advance after the depression of the land began and until the maxima both of the land subsidence and ice extension were attained, with a low altitude and even less descent of the lower Mississippi than now, has been well given by Le Conte in a paper before this Society.* The subsidence was doubtless slow, even though probably many times faster than the preceding uplift. It may have occupied only 5,000 years, being at a yearly rate of a half a foot to one foot; but possibly it was two or three times as long. While the slow sinking of the land was taking place, the accumulation of the ice by snowfall may have proceeded at a somewhat more rapid rate, so that the thickness of the ice-sheet and the altitude of its surface were increasing up to a maximum nearly coincident with that of the subsidence. Finally, however, the subsidence brought a warmer climate on the southern border of the ice, causing it to retreat, and giving to it in the region of the marginal moraines a mainly steeper frontal gradient and more vigorous currents than during its growth and culmination.

### Re-elevation during the Departure of the Ice-sheet.

When the ice-melting relieved this part of the earth's crust from its burden, and as fast as the ice-sheet receded, there followed a re-elevation of the land to nearly its present height. First at the south the region of the loess and of the driftless area in Wisconsin and adjacent states was uplifted so that the rivers speedily eroded much of their recently deposited fine glacial silt. The streams discharged from the ice-border during the formation of the moraines mostly flowed with strong currents, laying down gravel and sand beds along the bottoms of valleys bordered by high terrace remnants of the loess. Later the area of lake Agassiz was uplifted, causing its earliest upper beach to have a gradual ascent averaging about one foot per mile along an explored distance of 400 miles from south to north; and this uplift was rapid, being nearly completed before the formation of the lowest and latest beaches of this lake, which are almost or quite horizontal. The central and northern

* Bulletin G. S. A., vol. ii, 1891, pp. 329, 330. Compare Le Conte's Elements of Geology, third edition, 1891, p. 589.

portions of the lake area were uplifted 400 feet or more, and the greater part of the elevation took place during the first quarter or third of the lake's existence—that is, at a probable rate of about one foot yearly. Latest of all, the regions having postglacial marine beds above the till, including the basin of Hudson bay, the Ottawa and Saint Lawrence valleys, and the basin of lake Champlain, were raised from their partial marine submergence, so that these recent beds containing sea shells are 300 to 500 feet above the sea level. A wave of mainly permanent uplift followed and closely attended the recession of the ice-sheet from the southern boundary of the drift to the central district, where the ice was thickest and its remnants were doubtless latest melted away.

## Estimates of the Duration of the Quaternary Era.

The observations of the volume of the lake Agassiz beaches, as before stated, show for that lake a geologically very short existence, of about 1,000 years. All the conspicuous, far extended moraines, belonging only to the area of the later drift, were probably formed, like those traversing the lake Agassiz region, in a short time, apparently no more than twice that of the glacial lake. A similar or perhaps longer time seems to me requisite for the preceding reluctant and wavering recession of the ice, under the warm climate brought by the depression of the land, from its outermost limit across the area of the early drift to the first of these moraines. I am therefore led by this review to concur with Prestwich in his opinion expressed as follows, concerning the duration of the Ice age:

> For the reasons before given, I think it possible that the Glacial epoch—that is to say, the epoch of extreme cold—may not have lasted longer than from 15,000 to 25,000 years, and I would, for the same reasons, limit the time of . . . the melting away of the ice-sheet to from 8,000 to 10,000 years or less.*

Arranged in chronologic order, we have derived for the three parts of the Quaternary era, as here defined, the following estimates of their duration: the time of preglacial epeirogenic elevation, with the deposition and erosion of the Lafayette beds, some 60,000 to 120,000 years; the Glacial period, regarded as continuous, without interglacial epochs, attending the culmination of the uplift, but terminating after the subsidence of the glaciated region, 20,000 to 30,000 years, and the Postglacial or Recent period, extending to the present time, 6,000 to 10,000 years. In total, the Quaternary era in North America, therefore, has comprised probably about 100,000 or 150,000 years, its latest third or fourth part being the Ice age and subsequent time. The Tertiary era

*Geology, vol. ii, 1888, p. 534.

appears by the changes of its marine molluscan faunas to have been vastly longer, having comprised perhaps between two and four million years, of which the Pliocene period would be a sixth or eighth part, thus exceeding the whole of the ensuing era of great epeirogenic movements and resulting glaciation.

## *DISCUSSION.*

W J McGee: Mr Upham's communication is a highly interesting and suggestive one; but, in speaking of the Columbia and Lafayette formations as intimately related, if not essentially a unit, he falls into a serious error, though an error, perhaps, not surprising on the part of one who has not seen the formations in question. If there is one predominant general fact in the geology of southeastern United States, it is the fact of the unconformity between the Columbia and Lafayette formations, the greatest unconformity of the entire Coastal plain series, extending in time from the Cretaceous to the present, and in space from the Hudson to the Rio Grande. This unconformity represents erosion approaching, if not reaching, 1,000 feet in depth in the lower Mississippi region, and from 300 to 500 or more feet in depth at the embouchures of the other rivers of the Coastal plain, save, perhaps, off cape Hatteras, where the depth may perchance not exceed a hundred feet. The unconformity is represented by widespread erosion over areas individually embracing thousands of square miles, from which the entire formation has been removed, as in the Mississippi embayment area of 150 by 600 miles; it is represented not only by the removal of fully half of the original volume of the Lafayette formation, but by the degradation of an equal or greater volume of subjacent formations of Neocene, Eocene, and Cretaceous age beneath. The Columbia and Lafayette formations are by no means the deposits of a single period; they were not at all closely connected in time; the unconformity between them, representing erosion to an average depth of some hundreds of feet vertical over an area of some hundred thousand square miles, is the most impressive record of coastal plain history.

R. D. Salisbury: Our interpretation of Lafayette and Columbia in New Jersey must still be regarded as in some sense tentative; but, if we have interpreted correctly, the break between the Lafayette and the Columbia, instead of being a minor one, is one of great magnitude, representing a great time interval. It probably exceeds in importance any subsequent break in the geologic series.

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# SOME RECENT DISCUSSIONS IN GEOLOGY

ANNUAL ADDRESS BY THE PRESIDENT, SIR J. WILLIAM DAWSON

*(Read before the Society December 27, 1893)*

CONTENTS



## INTRODUCTION.

Our science has been characterized as one whose goal today is its starting-point tomorrow. Nothing, therefore, can be more suitable to an occasion of this kind than a glance at some of those questions at present most actively discussed, and on which we have within the last few months been reading the arguments and conclusions of some of our ablest workers. We may even venture to make some modest suggestions as to the manner of possible settlement of these questions, and thus aid in clearing the way for those advances which in the near future must leave our present standpoint far in the rear. Such a review must necessarily be discursive and fragmentary—a sort of conglomerate in its material, but some consistency may be given to it by regarding its several topics in their relation to the foundation and building up of our continents, one of the great leading points of geologic investigation.

## PRE-CAMBRIAN ROCKS.

Beginning with those ancient Archean or Eozoic formations, which are the foundation-stones of the earth, and in nearly every part of the world

may be seen to underlie the other members of our geologic column, we have recently learned from Sir Archibald Geikie * that the great controversies which have raged as to these rocks in the west highlands of Scotland ever since the order assigned to them by Murchison was called in question by my friend and fellow-student, Professor Nicol, of Aberdeen, has been finally settled. On comparing his arrangement with American facts, and especially those displayed in the unequalled exposure of these rocks in Canada, it would appear that the following correlations may be stated:

The older gneissic group of the west Highlands of Scotland does not contain the whole of the Laurentian of Logan, the Lewisian of Murchison, but only or mainly the lower part of it, the Ottawa group of the Canadian survey. A certain limited track at Loch Maree not improbably represents the Upper Laurentian or Grenville series, and this certainly occurs in the western islands. I use the term Upper Laurentian in the sense recently given to it by Dr Adams; † the original Upper Laurentian apparently consisting, in what was regarded as its typical area, mainly of igneous products. It is to be observed, however, in this connection that over large areas in the west the Upper Laurentian is absent, or has been removed, or is replaced by rocks of somewhat different character from those of the east.

I take this opportunity to object to the term "Archean or Basement Complex" applied by some geologists to these formations. Every geologic formation is complex, especially when disturbed and invaded by igneous rocks, but none is more simple than the Lower Laurentian, as it consists almost entirely of orthoclase gneiss; and even the igneous masses and veins have been introduced so quietly and with so little of the violence of modern vulcanism that it is not easy to separate them from the old beds with which they are so intimately united. I may add that it seems likely that the Lower Laurentian is the oldest formation we shall ever know, and that its peculiar characteristics depend on its constituting the earliest deposits from water on the thin crust of a lately incandescent globe.

The Torridon sandstones and the associated beds of Geikie seem in mineral character and in association with the Laurentian, and in the few fossils which they contain, to be equivalent to the Huronian of Logan. The Dalradian, at least in Ireland, would seem to be of similar character and age.

The Uriconian and Longmyndian of Geikie probably include the equivalents of our Kewenian, and the same may perhaps be said of the

* Journal of Geology, vol. 1, number 1, 1893.
† Journal of Geology, vol. 1, number 4, 1893.

Dalradian of Scotland. Some portions of these rocks may, however, be the same with what in Canada has been called by Matthew "Basal Cambrian."

It is evident that in Scotland, as in North America, the Laurentian rocks have been elevated into land before the deposition of the Huronian, and that the latter and the Kewenian are coarse littoral deposits clinging to the Laurentian shores, protected in part from lateral crushing by their hard Laurentian base, and represented at a greater distance from the old land by formations which have sometimes received different names, and which are usually in a state of greater alteration and compression.

It may be remarked here that in Canada, though the Laurentian beds are much folded and contorted, they are comparatively little affected by faults or overthrusts, and the succession is often extremely clear, while the outcrops of individual beds can be traced over great distances. This applies especially to the Upper or Grenville series, holding the great limestones and beds of graphite and magnetite and the serpentinous limestone containing eozoon.

The simple arrangement of the infra-Cambrian rocks as Kewenian, Huronian and Upper and Lower Laurentian is further vindicated by Walcott's section in the Colorado canyon, which shows them not only superimposed but unconformable. The lowest member is a granitic rock probably equivalent to the fundamental gneiss. Walcott has found in the upper part of the infra-Cambrian an obscure discina-like or stenotheca-like shell and a fragment resembling the cheek of a small trilobite. Still lower are the stromatoporoid masses of supposed *Cryptozoum.* Some specimens of this, recently sliced, show distinct traces of structure similar to that of Hall's typical species of *Cryptozoum.*

From long acquaintance with these rocks I conclude that the fourfold arrangement of Lower Laurentian, Upper Laurentian, Huronian and Kewenian will include them all, and that the name Algonkian, recently proposed, is merely provisional and equivalent to pre-Cambrian, which has been used to include rocks of uncertain classification in the base of or older than the Paleozoic.

## Mountain-making.

It is an easy transition from the old crystalline rocks to the mountain masses which so largely consist of them, and our knowledge of the foldings, crumplings and overthrusts of the older rocks certainly gives much help in the comprehension of mountain-making. Yet we must not forget that all mountains are not made up of old rocks folded and pushed over or under each other. Mountains of great magnitude, like Etna,

Vesuvius, and the cone of Cotopaxi, are built up of materials ejected from below in the manner of mole-hills or the dump of a mine. As I do not like the modern method of inventing grandiloquent names for structural features, I shall call this class "dump mountains." The most curious thing about them from our present point of view is the fact that they do not crush down the crust under them as sedimentary deposits would, and this, as any one can easily understand, depends on the circumstance that the very existence of such mountains is an effect of the upward pressure of matter beneath them. It may be said that such mountains are modern; but it is true that some very old elevations are remnants of the denudation of ancient piled-up cones.

Another class of mountains, which may be named "blister mountains," is produced by the gentle swelling up of the crust without any folding. Such mountains are the Catskills, the western Sierra, some mountains of old red sandstone in Scotland, and the high chain of Lebanon, which at its summit, 10,000 feet above the sea, presents horizontal beds of limestone falling away in mural precipices. Such mountains, unless supported merely by the heating and expansion of matter below, must be sustained by the horizontal injection of mobile matter beneath them. Hence the elevation of these mountains may imply much movement of softened rock beneath the crust, of a kind altogether distinct from lateral pressure at the surface.

The greater and more typical ranges of mountains, however, like the Alps and the Appalachians, are mountains of crumpling, showing evidence of enormous lateral pressure proceeding from the adjoining sea basins, and to this, it is now almost universally admitted, their elevation must be in great part due. We must note here, however, that in all great mountain ranges all these kinds of elevation are observed, for mountain-making on the great scale has implied not only plication but the elevation of plateaus and tablelands and volcanic ejections as well.

Two momentous questions arise here: Whence the pressure; and why has it acted along certain determinate lines?

The last of these questions comes first in order of time, for it seems established, and in this country has been well illustrated by Hall, Dana and Rogers, that the main lines of folding occur where the thickest sediments have been deposited along the borders of the oceans, and where, consequently, the lower parts of such sediments have been pushed by subsidence far down toward the heated interior of the earth. Again, whatever reasons may be urged against such a conclusion, it is evident that the crust underlying the oceans is the strongest of all, and that it must have been the pushing or resisting agent. The mountain regions of western America have, according to the Geological Survey of Canada,

been pushed eastward by the Pacific area more than two degrees of longitude, and Claypole affirms that the sediments of the Appalachians have been reduced to one-third of their original breadth by the pressure of the Atlantic basin.

All this is explicable at once on the old contraction theory, so ably expounded in this country by Le Conte. The thick resisting ocean basins have settled downward toward the center of the earth; they have at the same time caused the mobile matter beneath them to ooze out in volcanic ejections or to slide laterally under the lighter parts of the continents. They have thus exerted a great lateral pressure on their sides, much as the thick coating of ice on one of our northern lakes casts up ridges on its margin. It is objected to this that the earth is a rigid mass, and that the zone of lateral pressure by contraction is very superficial; but rigidity is a relative term—everything can be made to submit to adequate pressure; and however physical demonstration may establish the solidity of the earth, we may say as did Galileo, though in a somewhat different connection, we are sure, nevertheless, that it moves; and the sediments that make up the mountains are the thinnest possible veneer, the mere coat of varnish on an artificial globe, which can scarcely be laid on so evenly that it will not have inequalities greater than our mountains.

At the same time I see no reason why we should not avail ourselves of the expansion theory of T. Mellard Reade as well. The heated and swelling sediments may have thickened and twisted upward in aid of the lateral pressure caused by contraction. Nor need Dutton's theory of isostasy be left out, for the whole process of mountain-making seems to imply a certain flotation and pouring sideways of the potential liquidity beneath the crust, which is also evidenced by the volcanic ejections accompanying or consequent on the elevation, and which add to the product their injected masses and dikes, overflows of molten rock and ejections of fragmental material. The final result is that mountains can neither be built in a day nor by one cause only. When we have to fold great masses of rock into a third of their original width, to raise them thousands of feet into the air, and to sculpture the rude masses thus provided into grand and beautiful forms, we may well avail ourselves of all possible causes of elevation, as well as of those atmospheric and aqueous denuding agencies which give shape to the whole.

## Uniformitarianism.

In connection with mountain-making, as well as with other geologic changes, the well worn discussions as to uniformitarianism in geology have been refurbished, more especially in England, where Teall, in his

address as president of the geological section of the British Association, insisted on the unity of origin of the older crystalline rocks with their more modern successors, and the veteran Prestwich * has made a strong protest against an exaggerated uniformitarianism as applied to the later formations. Here also we need to beware of that one-sidedness which has led to so much unnecessary controversy from the days of Werner and Hutton down to the present time.

We may be fully prepared to admit that, on the hypothesis of a cooling globe, there must have been certain primitive rocks deposited as the first products of the action of a heated ocean on a still hot crust, conditions which would not again occur except in limited and exceptional cases. On the other hand, we know that ever since land and water existed, there must have been a certain uniformity and continuity of erosion and deposition. We may also in all this expect a kind of development whereby old rocks are wasting away and are redeposited in somewhat different states, but we must at the same time make allowance for the differences provided by alternate elevation and subsidence and by the occasional introduction of igneous products. So guarded, we may hold with truth that there has been a substantial uniformity of the origin and character of rocks throughout geologic time, though in every succeeding age the continents and the rocks composing them are different from their condition in any previous period. There has thus been uniformity with change and progress, but while the laws of nature and the operations under them have been uniform in kind, we must beware of supposing that they have been uniform in rate. In short, slow and gradual actions inevitably produce catastrophes or critical periods, and these again prepare the way for the recurrence of times of dull uniformity and scarcely perceptible motion. Slow and secular accumulation of sediments on limited areas or expansion and contraction of rocks may produce sudden and violent movement of the crust, just as we have seen lately the accumulation one by one of sheets of paper at length involve in sudden and utter ruin a great public building. A cliff long acted on by disintegrating atmospheric agencies at length falls instantly in a mass of fragments, and this prepares the way for new action of the atmosphere on the cliff in its protracted and infinitesimal way, and for the agency of the waters in removing the talus of fallen material.

The stupendous changes which we know our continents have experienced in the later Cenozoic periods and in times comparatively short, should warn us against exaggerated uniformitarianism, more especially when we find that this opposes invincible difficulties in the way of any rational explanation of such climatic changes as those of the Glacial

* Nineteenth Century, October, 1893.

period, or of the great continental movements which have interfered with the continued development even of man himself. It is especially with reference to these that Prestwich truly says that—

"The forms of erosion, the modes of sedimentation and the methods of motion are the same in kind as they have ever been, but we can never admit that they have always been the same in degree. The physical laws are permanent; but the effects are conditional and changing, in accordance with the conditions under which the law is exhibited."

I fear that the unreasonable uniformitarianism of certain modern schools of geology is a product less of scientific observation and induction than of the influence of certain philosophical dogmas. Lyell, the great author of rational uniformitarianism in geology, well understood the fact that catastrophe and cataclysm have their place in the grand uniformity of nature, and that long continued uniformities must lead to critical periods. He was not an agnostic or a believer in a necessitarian evolution. He saw in nature adaptations and a grand plan of development, including all changes, whether sudden or gradual; and I may add that it was this which gave that charm and fascination to his teaching, which caused one of his contemporaries to compare the interest of the Principles of Geology to that of an exciting romance. Dead materialistic uniformitarianism, should it ever become the universal doctrine of science, would provoke a reaction in the human mind which would be itself a cataclysm.

### Coal-making.

Of all the accumulations formed in geologic time probably the most slowly produced are those of organic materials; yet, curiously enough, even in the present exaggerated uniformitarianism there has been a endency here to return to exploded catastrophism. One can imagine some of those great beds of sandstone which occur in the Coal Measures, filled with trunks of trees piled in the most confused manner, to have been deposited by violent inundations; but when, after all that has been done to explain the origin of coal, we find some late writers returning to the old and exploded idea of the production of coal by driftage, we are tempted on the one hand to vexation, and on the other to laughter. In a very recent article in a well known journal I find in support of this theory the contention that underclays are not ancient soils, and the following sentences, alleged to be contradictory to each other, quoted from authorities on the subject. The first is as follows: "Underclays are old vegetable soils, and they were formed, not under water, but on dry land." Now underclays are certainly vegetable soils, but they were not neces-

sarily formed on dry land. They may be deposits from water, but may have been raised-up or filled-in to constitute soils. The second is: "Underclays are distinctly stratified, showing that they have been deposited under water." This is true of some of them at least, but is no argument against their having become soils. The subsoils of many swamps and marshes is a deposit from water, but land vegetation grows upon it. The imperfection of such statements and the absurdity of placing them in contrast are sufficiently obvious, yet such objections have to be met in the interest of scientific geology. They must be met exactly as they were met by Logan so many years ago in his observations on the underclays of south Wales, which have been followed up by myself and others. We have shown, in the first place, that the lycopods, ferns and calamites growing on these underclays were really land plants; secondly, that their roots penetrated the subjacent beds in such a way as to show that they have grown upon them, and, lastly, that the coal itself, in all cases except that of the cannel coals, bears evidence of subaërial accumulation, while the erect trees associated with it show that they decayed and became hollow by atmospheric action. No doubt the underclays were usually swamp rather than upland soils, but the occurrence of remains of land animals in erect trees shows that in some cases the soil must have been elevated ten feet or more above water level when the coal vegetation was growing on it. I have myself studied and described these facts as evidenced in the case of eighty successive beds of coal admirably exposed in the cliffs of the south Joggins.

In connection with all this we have the accumulation of five thousand feet of sediments and organic beds, each of which must in turn have been a land or shallow water surface, and the subsidence thus indicated must have taken place by small downthrows, only sufficient to keep pace with the accumulation of deposits, and this for a great lapse of time. The coal-deposits of the great Carboniferous system thus mark a special stage in the production of our continents, when they were less differentiated as to orography, and when a very uniform and equable climate extended over the northern hemisphere, accompanied by a very peculiar vegetation. Such conditions did not occur in combination and to a like extent in any succeeding period of the earth's history.

### Relation of Vegetation to continental Movements.

This special position of the great coal-formation leads to a consideration of the relation of vegetation and of fossil plants to the elevation and depression of our continents, to changes of climate, and to the determination of geologic age, and of which we are reminded by Professor White's

discussions of these subjects, and those in the recently published essay of Seward, as well as the posthumous report of Lesquereux on the flora of the Dakota group. I have already referred to the special conditions of the later Paleozoic in these respects, and am inclined to attribute the great geographic uniformity of its vegetation principally to the then unfinished condition of our continents, affording less local difference of elevation and greater uniformity in the distribution of ocean currents, though the larger proportion of carbonic dioxide in the atmosphere may have been also a determining cause. Yet, while there was little climatal difference of flora, there was continued change in time; so that wherever fossil plants occur, we can distinguish the vegetation of the Lower, Middle and Upper Devonian, of the Lower Carboniferous, of the Coal Formation, of the Upper Coal Formation, and the Permian. The great earth-movements of the Permian seem to have extinguished this flora by creating adverse climatic conditions, and in the Mesozoic age it was replaced by a new assemblage of plants, seemingly of southern origin, and adapted to an insular condition of our hemisphere. The later Cretaceous flora, with its wealth of modern exogenous genera, seems to have originated in the north and propagated itself southward, and the condition of things which led to a temperate flora in Greenland was connected with the occurrence of a great mediterranean sea between the Rocky mountains and the Appalachians, which determined the equatorial current upward through the interior of the American continent and threw its full force on Greenland, then probably less elevated than now. The geographic conditions of these ages of the later Cretaceous and early Cenozoic, we are now able to some extent to trace, and find them to correspond with the climatal conditions indicated by the plants. On the other hand, the changing physical conditions were correlated with those changes in the vegetation which have enabled us to recognize so distinctly the lower, middle and later Cretaceous floras, and those of the early, middle and later Cenozoic.*

While we have no evidence of a tropical climate in the northern part of America in the Cretaceous or the Cenozoic periods, we have proof from fossil plants of the continuance for long periods of a temperate climate as far north as Greenland, and that this passed gradually into the cooler temperature of the Miocene and Pliocene. We can also correlate these climatal conditions on the one hand with known geographic changes, and on the other with the distribution of animals and plants.

The validity of such deductions does not altogether depend on the accuracy of the reference of fossil species to existing genera or families. In many cases there can be little doubt as to this, as in the species of

* Trans. Royal Society of Canada, 1893. Paper on New Plants from Vancouver Island.

liriodendron, sassafras, platanus, sequoia and salisburia, and especially in the case of all those of which seed or fruit have been preserved; but even when the naming is inaccurate or when the number of species has been unduly multiplied, the deductions as to climate may hold good, though not perhaps to the extent of enabling us to fix a definite thermometric mean temperature.

As to geologic age, the primary requisite is that in some of the localities of plants in question their relative ages shall be determined by stratigraphic evidence; this being done in a few cases, it is not difficult to assign to their approximate position intermediate or allied subfloras. Plants treated in this way as evidence of geologic age have the advantage of wide distribution over the surface of the land, of slow migration and of long endurance in time. As in the case of animal fossils, we have to allow for differences of station, for possible driftage and intermixture of species belonging to higher and lower lands, and for chances of deposition and of preservation. We have also to consider that plants are more permanent and less changeable than the animal inhabitants of the land, and therefore better fitted to mark the longer ages of geologic time; but this is more than compensated by the closeness of their relations with the alternate elevations and depressions of our continents and the climatal relations dependent on them. A single leaf of some plant of a temperate genus found in arctic regions may thus bear explicit testimony to the former geography of a whole continent, and the climatal phenomena dependent on it; and thus aid us in understanding and referring to its true causes even the great Glacial period itself.

## Glacial Period.

I have recently been so venturesome as to add to the many publications on this vexed subject a republication of my numerous papers on phenomena of the Glacial period in America; and I am aware that many of my friends in this Society will dissent very widely from the views therein expressed. They will see, however, that I adhere very strictly to the physical possibilities of ice, and to the doctrine of existing causes, and that I have endeavored to take into account changes of geographic forms, and of climate dependent on them, and of all the varieties of land and water-borne ice anywhere to be seen in the colder portions of the earth at present. It is, I am convinced, only by taking all of these into account that we can succeed in explaining the complicated phenomena of this remarkable age; and we must be prepared also to allow for the movements of elevation and depression which seem to have occurred in that unsettled period, and of which many are fitted to produce a mini-

mum distribution of heat in the higher lands of our continents, while furnishing great oceanic areas for the supply of vapor. The accumulation of ice and snow and the production of great glaciers can occur only where there are not only large areas of abundant precipitation, but others of equally abundant evaporation. I would therefore ask the attention of my fellow-workers to the facts and conclusions presented in the volume referred to, and would explain that I have been induced by long and careful study of the phenomena, both ancient and modern, presented to observation in Canada to conclude that no one cause, however potent, can account for all these phenomena, and that we must invoke the combined and successive action of glaciers, of icebergs, of field, floe and pan ice, and, in short, all these glacial agencies that now operate in the north, and this in connection with great and unequal changes of level, producing elevation and submergence, the whole in such a way as to modify climate locally, and to some extent throughout the northern hemisphere. The problems presented to us by the Glacial period of the Pleistocene are thus very complex, and the great error here, as in so many other departments of geology, has been that of referring the effects of various causes and conditions, alternating through a considerable lapse of time, to one dominant cause without reference to others equally important. The time, however, is rapidly approaching when we shall no longer speak of opposed glacier and iceberg theories or invoke incredible physical changes to account for imaginary phenomena. I need scarcely add that our views of this whole subject have been greatly modified by the demonstrations that the close of the Glacial period dates only a few thousands of years before our own time, and that those astronomic theories, which demand a vastly greater time for their operations, are no longer tenable as the cause of a glacial period.

I may base some objections to the idea of a continental glacier as now held by many in this country on a suggestive paper by Dr Warren Upham * in the Bulletin of this Society, in which he institutes comparisons between Pleistocene and present ice-sheets. The present ice-sheets are stated to be four: 1. Antarctic or that which fringes the Antarctic continent and is probably better entitled to the name than any other, but which differs from the supposed ice-sheets of the Pleistocene in fronting on the sea and discharging all its product as floating ice. In this, however, it certainly resembles many of the great local glaciers of the Pleistocene. 2. The great névé of Greenland, which, however, discharges by local glaciers, opening on the sea. 3. The Malaspina glacier of Alaska, evidently a local glacier of no great magnitude, though present-

*Comparison of Pleistocene and present Ice-sheets. Bull. Geol. Soc. of America, vol. 4, pp. 191–204.

ing some exceptional features. 4. The Muir glacier of Alaska, also a local glacier, but perhaps, like the Malaspina, showing some features illustrative of local Pleistocene glaciers.

In the "conferences and comparisons," however, the facts detailed in the earlier part of the paper are placed in comparison with postulates respecting the Pleistocene which are incapable of proof: 1. It is taken for granted that the upper limits of glaciation in the mountain ranges of America indicate the thickness of a continental ice-sheet. They probably indicate only the upper limit of the abrasion of local glaciers. 2. Hence it is computed that the thickness of a continental glacier flowing radially outward in all directions from the Laurentian highlands of Canada amounted to two miles, and in connection with this it is stated that the maximum thickness of the great Cordilleran glacier of the west in the Pleistocene age has been estimated to be about 7,000 feet, an entirely different thing and referring to the maximum depth of a local glacier traversing deep valleys. 3. It is admitted that the assumed continental glacier could not move without an elevation of the Laurentian highlands to the height of several thousand feet, of which we have no evidence, for the cutting of the deep fiords referred to in this connection must have taken place in the time of Pliocene elevation of the continents before the Glacial period. 4. The upper and lower bowlder-drift, so different in their characters, are accounted for on the supposition that the former comes from material suspended in the ice at some height above its base, the other from that in the bottom of the ice. In like manner the widely distributed interglacial beds holding remains of land-plants of north temperate character are attributed to such small local occurrences of trees on or under moraines as appear in the Alaska glaciers. 5. The rapid disappearance of the ice is connected with a supposed subsidence of the land under its weight, though from other considerations we know that if this was dependent on such a cause it must have been going on from the first gathering of the ice, so that the required high land could not have existed. All the evidence, however, points to subsidence and elevation owing to other and purely terrestrial causes, and producing, not produced by, the glaciers of the Pleistocene.

The question of erosion by glaciers is still agitated. My own conclusions, formed from the study of the Savoy glaciers in 1865, is that glaciers are never important eroding agents, that in valleys they protect the rock from the greater denuding action of streams, and that the mud and sand which they produce are derived not from the rocks in which they slide, but from the material that falls upon the glacier. The bottom rock is merely the nether millstone.

One of the most experienced of alpine geologists, Professor Bonney, in

a paper read before the Royal Geographical Society,* discusses this question in detail and arrives at the same conclusion which I stated in 1866, namely, that glaciers are "agents of abrasion rather than erosion," and that in the latter their power is much inferior to that of fluviatile action. Nor are glaciers agents in the excavation of lake-basins, which are to be accounted for in other ways; and the great gorges and fiords which have been ascribed to them are due to aqueous erosion when the continents were at a higher level, before the glacial age.

Lastly, on this subject, very important facts have been ascertained by the Geological Survey of Canada and by United States observers in Alaska, indicating that during the height of the Glacial period there was an open arctic basin in the north. This coincides with the fact stated by Professor Penhallow† and myself in a previous volume of the Bulletin of this Society, that in the Pleistocene period the flora of Canada was boreal rather than arctic; consequently the arctic flora must have maintained its ground farther north. In northern Europe, Nathorst and others have shown a southward movement of the Scandinavian flora, but this does not seem to have been general, and the recent work of Lange and Warming on the flora of Greenland proves that the persistence of the arctic flora in the north applies even to that country, whose condition as to climate does not seem in the Pleistocene to have differed much from that of the present time. It is not impossible that, as Howorth has suggested, the north Polar regions are colder now than in the Pleistocene, that the cold of that period was thus more local than has been supposed, and that we may find that even the mammoth was able to hold his ground in the north throughout the great Ice-age.

Allow me further to say that these facts tend to confirm the conclusions already stated in this address, that we are to look, for causes of change of climate, rather to movements of elevation and subsidence of the continents than to any extra-mundane influences.

## Post-Pleistocene continental Movements.

We come now to the last great vicissitude of our continents, one that is beginning to connect itself with the history of man himself. No geologic fact is more certain than the occurrence of a period of continental elevation after the great Pleistocene submergence, and that this period coincided with the spread of postglacial or palanthropic man over the continents of the northern hemisphere. It is equally certain that within

*Geographical Journal, July, 1893. See also J. W. Spencer: Quart. Jour. Geol. Soc. of London, 1890, p. 523.

†On the Pleistocene Flora of Canada. Bull. Geol. Soc. of Am., vol. i, pp. 311–344.

a time measured by a few thousand years this continental period terminated, and the continents subsided to their present limited dimensions, permanently submerging some of the fairest portions of the former abodes of man and for a time inundating vast areas of the land. It has, however, been a much debated question whether these great changes were gradual or sudden, and whether they were connected with the disappearance of palanthropic man and his contemporaries. I have myself long maintained the conclusion that the human period is on good geologic evidence divided into two portions by great earth-movements, and that it is the historical traditions of these which constitute the foundation of that universal belief of a deluge which has fixed itself in the memories of ancient men in every part of the world.

The great English geologist, Prestwich, has recently given much attention to this subject, and in a memoir in the Transactions of the Royal Society of London * has adduced a mass of evidence on which he bases the conclusion that an important movement of subsidence and reëlevation occurred at the end of the Glacial or post-Glacial period, and was of the character of a somewhat sudden inundation destructive of man and animals. The deposits produced by the recession of the waters of this inundation he designates "rubble-drift," a formation which overlies the glacial deposits and indicates a movement of water distinct from anything belonging to glacial phenomena or to ordinary river inundations. He includes with this the deposits known as "head" in England and also the loess of the plains and tablelands of Europe and the material found in certain caves and fissures. He might have added some of the gravels and superficial deposits of Egypt and Syria, and modern deposits extending far east into central and northern Asia. Thus we now have geologic facts which show that man has been a witness of one great continental submergence, which must have intervened between the close of the Glacial period and the present time. These facts at once establish a remarkable correlation between the results of geologic investigation and the historic deluge, and expose the fallacies of those theories which assume an uninterrupted progress of man from his first appearance until the present day. A curious confirmation of this has recently been furnished by the excavations of Nuesch in a rock shelter near Schaffhausen,† which show an overlying deposit with neolithic implements and bones of recent animals, a bed of rubble and loam destitute of human remains, and below this a bed containing bone implements, worked flints and traces of cookery of the palanthropic period. The whole rests on a bed of rolled pebbles supposed to be the upper part of the glacial de-

*Vol. 184, 1893, p. 903.

†Nouvelles Archives des Missions, etc., vol. iii; noticed in Natural Science, 1893.

posits. This shows the interval between the palanthropic and neanthropic periods, and also the post-glacial date of man in Switzerland. It corresponds with a great number of other facts.

I cannot doubt that evidences of the second continental period exist in America. Those which are afforded by the warm-water fauna of the southern bay of the Gulf of Saint Lawrence I pointed out many years ago. There are also superficial deposits which show depression since the glacial age, though I fear that many of them have been confounded with the ordinary drift, and I think the attention of geologists who study these more recent deposits should now be directed to the separation of rubble drift, head and loess from the beds properly belonging to the Glacial period, and to the bearing of these facts on questions as to the possible occurrence of man in America in the Palanthropic age.

## Preglacial Man.

I confess that I have all along been skeptical on geologic grounds as to the numerous finds of paleolithic implements in the glacial gravels. The gravels themselves are probably in many instances postglacial, and it is doubtful if the implements belong to these gravels or are merely superficial. The observations of Mr W. H. Holmes, of the United States Geological Survey, seem now to have confirmed these doubts, very notably in the case of the celebrated Trenton implements. With the aid of a deep excavation made for a city sewer he has shown that the supposed implements do not belong to the undisturbed gravel, but merely to a talus of loose débris lying against it, and to which modern Indians resorted to find material for implements and left behind them rejected or unfinished pieces. The alleged discovery has, therefore, no geologic or anthropologic significance. The same acute and industrious observer has inquired into a number of similar cases in different parts of the United States, and finds all liable to objections on the above grounds, except in a few cases, where the alleged implements are probably not artificial. These observations not only dispose, for the present at least, of paleolithic man in America, but they suggest the propriety of a revision of the whole doctrine of paleolithic and neolithic implements as held in Great Britain and elsewhere. Such distinctions are often founded on forms which may quite as well represent merely local or temporary exigencies or the débris of old workshops as any difference of time or culture. All this I reasoned out many years ago on the basis of American analogies, but the Lyellian doctrine of modern causes as explaining ancient facts seems as yet to have too little place in the science of anthropology.

The question, however, still remains whether there is any evidence of

the occurrence of postglacial or palanthropic men in America, as distinguished from the modern American Indian, and, if so, whether any geologic evidence exists of his having shared in the diluvial catastrophe so destructive to his old-world confreres.

The collections now being accumulated by Putnam in the Peabody Museum at Cambridge, will do something toward settling these questions, if properly aided by the work of geologists in the field, and it would be a triumph for American science to remove them from the doubt and difficulty which now surrounds them; but the geologist, rather than the archeologist, must assume the responsibility of establishing the true age and sequence of the deposits.

I began with the statement that our goal today will be our starting-point tomorrow, and have endeavored to attract your attention to a few of the questions which are being agitated today. What tomorrow may bring forth it remains for my successors to tell. I may conclude with thanking you for the honor you have done me in placing me in this presidential chair, and by expressing my sincere good wishes for the prosperity and usefulness of the Geological Society of America.

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# GEOLOGICAL NOTES ON SOME OF THE COASTS AND ISLANDS OF BERING SEA AND VICINITY

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(*Read before the Society December 27, 1893*)

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## INTRODUCTION.

The notes here presented are those made during an extended cruise in the Bering sea region during the summer of 1891. The writer was at the time more particularly engaged in the investigation of matters connected with the fur-seal, as one of the British commissioners appointed for that purpose, but his somewhat prolonged familiarity with the geological features of British Columbia and adjacent parts of northwestern Canada caused him to feel a special interest in the corresponding features of the

various places visited. The time available for observations ashore was usually very limited, and thus, but for the fact that so little is yet known respecting the geology of the whole region, such notes as it was possible to make would possess very little inherent value. As it is, they may be accepted as a slight contribution to our knowledge of a portion of the globe of which but a few limited spots have yet come under the observation of any trained geologist.

Dr W. H. Dall has lately collected in a single work a précis of nearly all the authentic data relating to the American shores and islands of Bering sea.* This work is devoted specially to the Neocene formations, but these include a great part of those known to occur, and references are besides given in it to various older formations. Allusion is frequently made to this work of Dr Dall's in the sequel, and in so far as they cover

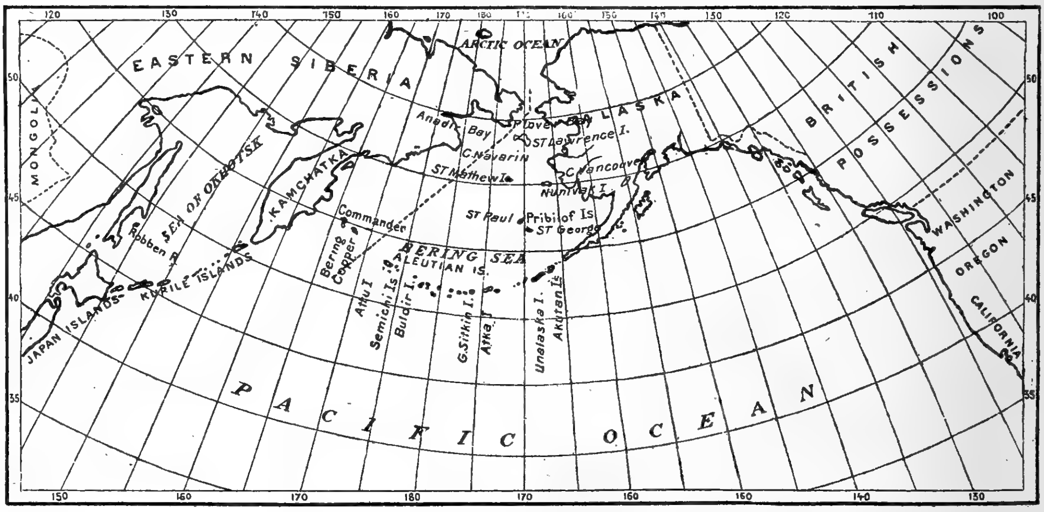


FIGURE 1.—*Map of Coasts and Islands of Bering Sea.*

the same ground the notes here set down may be regarded as merely supplementary to those he has published either as the result of his own observations or in the form of extracts from older works. Thus in what follows respecting the Aleutian islands, it will be found that only those touched at or seen by the writer are mentioned, and, generally speaking, that greater attention is given to places about which the known facts are particularly scanty or altogether wanting, and to those more general physiographic features of the land to which the attention of the earlier explorers was not directed.

Mr W. F. Ferrier, lithologist to the Geological Survey of Canada, has been so kind as to look over the rock specimens brought back, and in some cases has examined them microscopically in thin sections for the purpose of their determination.

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*Bull. U. S. Geological Survey, no. 84, 1892, p. 234 et seq.

## ALEUTIAN ISLANDS.

*Akutan Island.*—The south side of this island was the first part of the Aleutian chain sighted by us in approaching Bering sea. It is characterized by rugged and bold cliffs, broken into stacks and pinnacles at the points, but between retiring into coves and bays, from some of which rather wide valleys run inland. The varied and often strongly contrasting coloring of the weathered rocks in these cliffs, together with the absolute treelessness of the land and the vivid green of the sward and herbage with which it is covered wherever not too rocky or too elevated for any growth, were the most striking features. These, however, are almost equally found in all the islands of the Aleutian chain.

Steep and irregular hills and ridges rising from the shores culminate in the central part of the island in mountains sufficiently high to carry

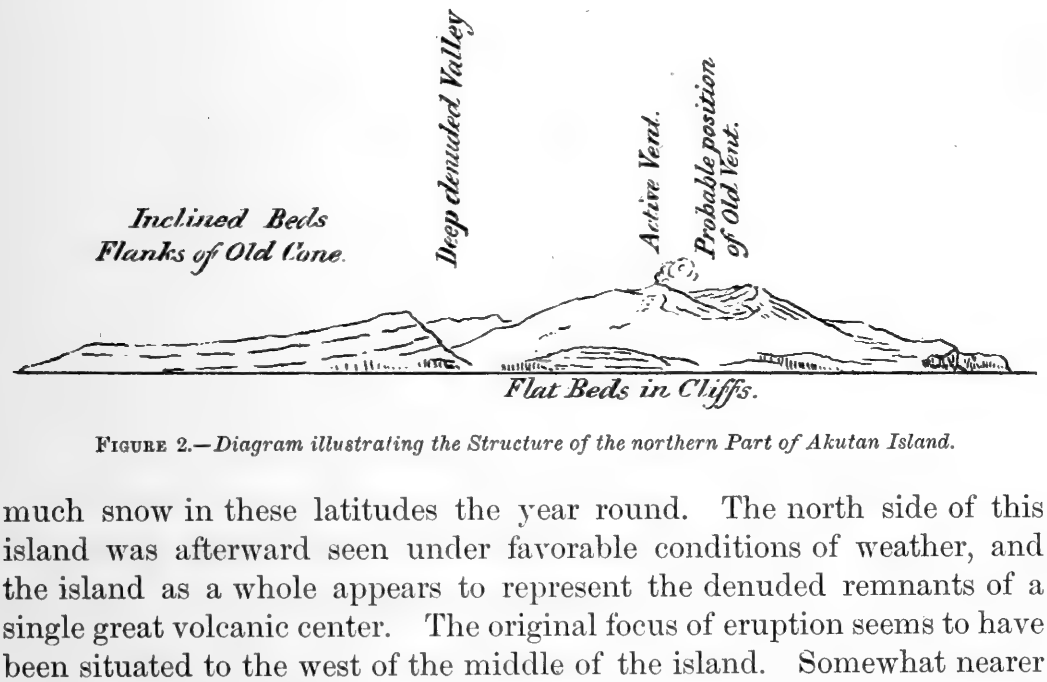


FIGURE 2.—*Diagram illustrating the Structure of the northern Part of Akutan Island.*

much snow in these latitudes the year round. The north side of this island was afterward seen under favorable conditions of weather, and the island as a whole appears to represent the denuded remnants of a single great volcanic center. The original focus of eruption seems to have been situated to the west of the middle of the island. Somewhat nearer the actual center of the island a little cloud of steam still issues from one of the higher points, and occasional small eruptions have been noted.*

The eastern portion of the island shows part of the lower slope of the original great volcanic cone, the beds flattening out gradually to the eastward in conformity with the decreasing slope of the surface.

The antiquity of the volcanic action to which the island as a whole owes its origin, is shown by the amount of the subsequent effect of denudation upon it. The deep valleys have evidently been cut out by ordinary subaërial erosion during a prolonged period of waste, and many of the

* Alaska and its Resources: Dall, pp. 467, 470.

lower ridges and hills owe their present forms entirely to such action The peripheral parts of the island have during the same period been much reduced and cut back by the sea.

The cliffs along the south shore and those about the middle of the north shore display bedding, which in the planes of section appears nearly horizontal. The individual beds are for the most part thick, and some of them show a pronounced basaltic structure.

*Unalaska Island.*—Respecting the island of Unalaska little can be added to the notes lately brought together by Dr Dall.* A good view was obtained of that part of the north coast between Makushin and Captain's bays, behind which rises Makushin volcano, the highest mountain (5,474 feet) on the island. The upper parts of this mountain and the high ridges about it were deeply covered with snow in August, and small, irregular glacier masses, more or less crevassed, were observed here and there.

Makushin is not a typical volcanic cone, but an irregular, lumpy mountain mass with some rather bold spurs and crests even about its upper parts, which seem to evidence considerable waste by denudation since the latest important eruptions. A cloud of white steam still, however, hangs about its summit. The natural processes of waste have not acted sufficiently long upon this island to produce rounded forms or light slopes. The hills are generally sharp edged, peaked and bold, but often covered with herbage nearly to their tops.

The shore-cliffs, from abreast of Makushin to Captain's harbor, show horizontal or slightly inclined bedding, which is rather too fine and uniform to be explained as that of superposed lava flows. The beds exposed probably consist of scoria or volcanic ash deposited under water. Dall notes the occurrence of marine Miocene deposits in Makushin bay.†

The slopes and hills about Captain's harbor were all closely scanned for evidence of old beachlines, but none were seen. There appears to have been no notable upward movement of this land since the denudation which produced its present form took place. The little flat about the village of Unalaska is composed of gravel covered with black soil, and is about twenty feet above high-water mark. Its occurrence might almost be explained as a beach deposit at the present storm level, but it more probably indicates a very slight rise of the land.

*Atka Island.*—A call was made at Nazan bay, on the east side of Atka island. This island, with others near it which were more or less imperfectly seen, appears to be practically entirely composed of volcanic rocks. Some interesting notes on Atka are given by Dall in the publication

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* Op. cit., p. 242.

† Op. cit., p. 243. In addition to the volcanic rocks of various kinds, Dall mentions the occurrence of granite or syenite [gabbro ?] in the interior of this island. Op. cit., pp. 233, 242.

already quoted (pages 243–244), from which it appears that in Karovinski bay, on the west side of the island, pieces of fossil wood, sometimes silicified, as well as marine Miocene fossils in tuffaceous volcanic deposits, are found. The little islands in Nazan bay and the low projecting points about it have a basaltic appearance and rather irregular columnar structure. The rock showing on the beach, at the village, is a greenish gray, fine grained material, very hard and in places containing many grains of iron-pyrites, probably clastic and apparently a diabase, though not microscopically determined. It is also traversed by small drusy veins of quartz, and large loose masses of quartz were found which had evidently not travelled far.

In a small brook, which has cut out a little ravine near the village, a considerable depth of superficial earthy material is exposed. This exhibits a certain amount of stratification parallel to the slope of the ground. It is brownish or reddish brown in color, and appeared to be composed of volcanic detritus, which has either been deposited in the sea when the land was at a somewhat lower level, or perhaps more probably merely washed down the slopes while in an incoherent and fresh state. Material of the same kind was recognized elsewhere on this and other islands of the Aleutian chain, sometimes in rather notable quantity.

No indications of old terrace levels were observed about Nazan bay, but around the base of the mountain which forms a projecting point to the north of the entrance of the bay, three or more successive, indistinct terrace-like markings occur, the highest being at an elevation of about 1,000 feet above the present sea level. These markings may represent old beachlines impressed in soft material, but from their indefinite character this remains uncertain.

*Great Sitkin Island.*—After passing Atka island a fine general view of Great Sitkin island was obtained. This evidently consists of a single large volcanic cone, which, according to the charts, is still 5,033 feet high. Its upper portion was heavily covered with snow.

*Buldir Island.*—Buldir island was passed sufficiently near to enable it to be well seen. Its eastern end is most elevated, and high cliffs there show a series of flows or beds of volcanic material, dipping rather steeply westward. The angle of dip gradually diminishes and the stratification becomes horizontal at the west end of the island, the general height of the surface decreasing in a corresponding degree. The whole island clearly represents the residual portion of an originally symmetrical volcanic mountain, the greater part of which has been cut away by the sea.

*Semichi Islands.*—The Semichi islands form a narrow chain, broken by two small gaps, and about fourteen miles in total length. They are un-

usually low and flat, the highest point, at the western end, being, according to the chart, about 800 feet. The islands slope down to the southward with nearly uniform grassy surfaces.

*Attu Island.*—This is the westernmost island of the Aleutian chain. It appears to be throughout mountainous, and, in its general contour, with steep, grassy elevations, closely set, is not unlike most of the larger islands of the chain. Its highest point, according to the chart, is 3,084 feet.

My observations were confined to the vicinity of Chichagof harbor, on the north side of the island. At the east end of the gravelly beach at the bottom of the harbor, hard, greenish gray rocks occur, possibly diabase in composition, but too fine grained for macroscopic determination. These are in some places distinctly bedded and probably clastic, the dip being north 65° west (magnetic), at an angle of 45°. Similar rocks, with a similar dip, appear on the opposite side of the harbor at the west end of the same gravel-beach, and were again found at the summit of the mountain or high ridge on the east side. The rocks of Gibson island, off the mouth of the harbor, were observed to be bedded with such unusual regularity that this island was specially visited. They proved to consist for the most part of much altered and indurated volcanic materials, with purplish, greenish and gray colors. Perhaps the most abundant material is a medium grained rock, which in some specimens is evidently an eruptive, in others probably clastic, and very possibly a diabase in composition, but fine grained clastic felspathic rocks also occur, which pass into a black compact material which is apparently a true argillite. Though sought for, no fossil remains of any kind could be found. The dip is here north 30° east (magnetic), at an angle of 40°.

The rocks seen in the harbor closely resemble those noted in Nazan bay, Atka island. The general lithological character and degree of alteration of the rocks of this part of Attu island resembles that of some of the Mesozoic rocks of British Columbia, particularly parts of the Triassic series as represented there, and though such a criterion is of very limited value, Dall may not improbably be correct in his conjecture that they are of Mesozoic age.* In any case, the high angles at which these rocks lie and the amount of alteration and denudation which they have suffered show that beds much older than those referable to modern or even late Tertiary volcanic action are included in the composition of this part of the Aleutian chain.

Dr Dall states that Attu is destitute of modern volcanic rocks, and my observations, so far as they go, are to the same effect. Even in the gravel

* Op. cit., p. 344. The occurrence of Triassic rocks in the peninsula of Alaska is indicated by specimens from that peninsula shown to me by Mr R. Neumann, of Unalaska. These consist of the Monotis-bearing argillite of that formation.

of the beaches such rocks appear to be wanting. The pebbles consist chiefly of materials like those observed to occur locally, but a considerable number of gray granitoid fragments were also observed along the shores, of which the origin is uncertain. It is noteworthy that though this island thus appears to be composed of older rocks than most of the Aleutians, its topographic forms are not dissimilar from those of the other islands. No distinguishing features are, for example, apparent between the hills surrounding Chichagof harbor and those near Captain's harbor in Unalaska.

About Chichagof harbor there are some well marked old seacliffs rising behind gravelly flats of twenty or thirty feet in height, and such as to indicate an elevation of the land by that amount since their formation. On the slopes of the ridge on the west side of the harbor, several faintly impressed horizontal lines also appear, the highest being about 300 feet above the sea. They seem to represent incipient terraces, and, if so, must indicate a somewhat rapid elevation of the land, such as to prevent any long continued marine action at any particular level.

## Commander Islands.

Bering and Copper islands, with a few adjacent rocks and reefs of no importance, form the Komandorski or Commander group appurtenant to Russia and subsidiary to the government of the Amur. The two islands are parallel in trend, lying in northwest by southeast bearings. They are separated at their nearest points by a distance of 26 nautical miles. Copper island, which lies farthest to the eastward, is divided by 190 miles of deep ocean from Attu, the easternmost of the Aleutian chain, while Bering island is distant some 95 miles from the nearest part of the peninsula of Kamchatka. The high volcanic mountains of the peninsula may in clear weather be seen from Bering island, but the latter is probably never under any circumstances visible from the mainland. In view of the fact that the Aleutian islands were, when discovered, rather thickly inhabited, and that evidences exist on them of inhabitants long antecedent to historic times for the region,* it is somewhat remarkable that the Commander islands appear never to have been visited by man previous to their discovery by the Russians in 1741. The climate of these islands is humid and cool, insuring a luxuriant growth of grasses and herbaceous plants of various species wherever there is sufficient soil, but though less rigorous than that of the lands in similar latitudes on the eastern side of Bering sea, no trees or shrubs are anywhere found upon them.

* Dall in Contributions to North American Ethnology, vol. i.

*Bering Island.*—Bering island is about 50 miles in extreme length, with a width of nearly 20 miles at its northern and wider end. From this it narrows gradually, but irregularly, to cape Maniti, its southeastern extremity. The northern half of the island is low, with a rolling or nearly flat surface, much of which is described as consisting of "tundra" land. It includes one large lake, which discharges on the north shore. The southern half is higher, and appears, as seen from the sea, to consist of a mass of rounded hills, varying in height from several hundred to perhaps 1,000 feet. There are no harbors about the island, but a fair anchorage, with off-shore winds, may be found in a bay at Nikolski, on the west coast of the island, about ten miles from its northern end. The only permanent settlement, with the headquarters of the Russian government of the islands, is situated at this place.

The shores of the higher southern portion of the island are generally bordered by cliffs or steep scarped banks, with narrow and V-shaped valleys breaking through them to the sea.

On the east side of cape Maniti, and for some miles northward, regularly stratified rocks in rather thin beds of pale brownish colors were observed, dipping regularly northward at an angle of about 15°. Farther to the northwestward, along the same eastern coast, at cape Tolstoi (thirteen miles from cape Maniti) paler fawn-colored or cream-colored beds were seen, dipping away from the shore at low angles. They are crumbling and incoherent in character, and produce long slopes of débris in some places between the bluffs and the sea. Similar rocks apparently continue from cape Tolstoi to Stareya bay, at a further distance of nineteen miles, but the cliffs become lower and the scarped banks are less steep.

A landing was effected at Stareya bay, when it was found that the scarped slopes, which often resemble sand from a distance and are so described in sailing directions, are in reality composed of angular and rubbly fragments of whitish, yellowish and gray argillites or shales, with crumbling sandstones and argillaceous, fine grained gray limestones. All these rocks are well bedded, and on some surfaces small carbonaceous plant fragments were observed, though none of these were determinable. The material of the beach is composed almost entirely of the débris of similar rocks, and it is probable that the whole northeastern coast of the island, at least this far, consists of moderately indurated sediments of Tertiary age, regularly bedded and present in considerable or great thickness. The browner beds of the vicinity of cape Maniti may, however, be tuffaceous volcanic material. While it is not improbable that basaltic or other volcanic rocks may also occur, as some such were found upon the shore, they were not actually seen in place. No

crystalline or other evidently foreign rocks were found upon the beaches. The soil in the valleys and on the lower slopes of the hills is a reddish, fine grained material, doubtless formed by the disintegration of the rocks above described.

No satisfactory general views of the coastline of the northern and lower part of Bering island were obtained on account of foggy weather. A landing was, however, made on the north shore at cape Yushin, where the "north rookery" is situated. The shore is here rocky, and wide, low reefs run out from it, entirely composed of volcanic rocks. One of these is a dark brown melaphyre, containing plagioclase, augite and olivine crystals, with some magnetite, embedded in a groundmass of the same constituents. There is also a fragmental rock of somewhat peculiar appearance, which seems not to be a true agglomerate, but an eruptive material charged with fragments of dissimilar rocks. The basis is somewhat amygdaloidal, and may very probably have the same composition as the rock first noted. Well formed pyroxene crystals are abundant in some parts of the mass. The rocks are much shattered, and it was not easy to determine the precise relations of the two varieties here associated. No trace of sedimentary rocks like those of Stareya was seen.

At Nikolski, on the west side of the island, the point south of the little bay is composed of hard, fine grained, gray, augite-porphyrite, composed of plagioclase, augite, and a light brown biotite, considerably altered to chlorite, apatite and magnetite. It is homogeneous in texture and apparently massive. Here and there this rock is curiously spotted with flesh-colored chalcedony, which occurs in it in small kernels not distinctly amygdaloidal. The relation which this rock may bear to the stratified sediments of other parts of the island remains uncertain, as no sedimentary rocks were seen here. Basaltic rocks are, however, probably abundant in the northern part of the island, for fragments of such rocks are common on the beaches.

The shores about Nikolski in some places show a well marked low terrace, at twenty to thirty feet above high-water mark, which evidently indicates an elevation of about that amount, as there is a second still lower flat just above the actual beach, which may be accounted for by the accumulation of storm-wash under the present conditions or very nearly so. This lower flat is no doubt that in which the *Rhytina* bones were found to be most abundant by Nordenskjöld. With these exceptions no terracing was observed in Bering island. According to Mr N. Grebnitsky, the governor of the Commander islands, some fossil shells and plants have been found in the rocks of Bering island, which, on transmission by him to Saint Petersburg, were referred to the Miocene Tertiary. Lignite is also found on the island, but in inconsiderable

quantity. Nordenskjöld gives some general notes on Bering island, and quotes a statement made to him by Mr Grebnitsky of a character similar to the above.*

To the south of Nikolski the western shore of Bering island was not seen.

*Copper Island.*—Copper or Medni island is about thirty miles in length, with a greatest width of about five miles, to the south of the middle of the island. It forms a single mountainous ridge, of which the highest parts probably attain an elevation of 3,000 feet, and is much bolder in outline than Bering island. Its surface is exceedingly irregular, and comprises very little flat land of any kind, while its shore is often bordered by high and rugged seacliffs, particularly along the southeastern side. The shoreline of this side is sinuous, while that of the northeastern side is deeply indented by several considerable bays, but affords no good harbors for large vessels. There are three small settlements on the northeast coast—Glinka, Karabelny and Preobajenski—the last named being the most northern and the only one continuously occupied during the winter months.

The island appears to be almost entirely composed of volcanic rocks of some antiquity. No volcanic cones or craters were observed, but, on the contrary, the existing relief is evidently the result of oridnary denudation. The slopes are generally steep and are sometimes surmounted by rocky crests, but are usually more or less completely grass-covered from base to summit. The hills in their form and general appearance much resemble those of the higher parts of Saint Matthew island.

Copper island was crossed near its southeastern end from Glinka (Pestchanni of some charts). At Glinka the rocks seem to have a general southeasterly dip, and both here and on the other side of the island are for the most part gray and brownish porphyrites (augite-porphyrite?), with some massive beds of coarse agglomerate. Where the scarped slopes of the southwest side of the island were first reached, a bed ten to twenty feet in thickness of a soft pale tuffaceous rock was found. This consists of small fragments and fine amorphous material, all apparently volcanic in origin, and contains embedded pieces of tree-trunks, sometimes more or less silicified, but more usually in the form of lignite. The tuff was observed in some instances to fill what had originally been hollows in the rotten wood. Below this is a bed ten feet or more in thickness of coarse conglomerate with well rounded stones, which also contains lignitized fragments of trees. The pebbles from the conglomerate consist of volcanic rocks similar to those common in the vicinity, and the whole of the water-bedded intercalation appeared to be referable to the temporary

* Voyage of the Vega, vol. ii, pp. 280, 291.

occurrence of beach conditions during a stage of the period of volcanic activity to which the rocks of the island generally are due. The dip at this place is southeastward at an average angle of 15°.

In the valley behind Glinka village pretty definite evidences of terracing were observed at several different levels. The horizontal lines are, however, but faintly impressed. The highest of these was estimated to be 600 or 700 feet above the present sealevel.

At Preobajenski, near the northwestern end of the island, the rocks seen were chiefly greenish and purplish porphyritic materials, of which no specimens were brought back. The rocks which form a high cliff to the north of the village at this place were not examined. They are well stratified and dip in a southwestward direction at an angle of about 40°. There is, however, nothing in their appearance to indicate that they differ in origin from the volcanic materials elsewhere characteristic of the island. The native copper from which this island takes its name is found at its northwestern extremity, and specimens of it were given to me by Mr Tillmann, the government officer in charge of the island. Most of these are rounded nuggets and pellets, which had evidently been picked up on the shore, but some of them still include fragments of volcanic rock, gray or reddish, and very probably an agglomerate. A few unworn pieces in the form of sheets or more or less dendritic and crystalline fragments must have been freshly broken from the containing rock.

The occurrence of copper at this place has long been known,* and as early as 1755 the Russian government sent a mining engineer named Jakovlev to report upon it.† It is believed that his report was unfavorable to the value of the deposits.

## Kamchatka.

Favorable weather enabled a remarkably good general view to be obtained of part of the Kamchatkan coast, in steaming along it from the latitude of Bering island to Avacha bay. Its most striking feature is the series of great volcanic mountains which occur in general parallelism to the axis of the peninsula. Klotchewsky, according to the charts, is over 16,000 feet in height, while Kronotzki, Japounski and Koranski attain 10,608, 9,218 and 11,406 feet respectively. Several of these mountains possess remarkably symmetrical conical forms, unchanged by denudation and indicating continued growth and repair by volcanic forces still near the period of their greatest intensity. Shishaldin and one or two other mountains seen in the Aleutian islands show an approach to

* Account of the Russian Discoveries between Asia and America, Coxe, pp. 123, 206.

† Voyage of the Vega, vol. ii, p. 275.

such regularly conical forms, but taken as a whole the volcanoes of the Aleutian chain, as compared with those of Kamchatka, are but stunted and irregular, the general impression conveyed by such a comparison being that of the much greater age and dwindling condition of vulcanism in the Aleutian region, where the processes of waste have for a long time outstripped those of accretion.

Besides the dominant volcanic cones, covered or heavily striped with snow, there is much irregularly mountainous or hilly country of lower elevation. Very possibly this also may be largely volcanic in origin, but if so it has been denuded and sculptured into ordinary systems of hills and valleys like the mountains of most of the Aleutian islands already described, probably in later Tertiary times.

There is also, along this part of the coast, evidence of a plane of marine denudation. This plane was observed particularly about cape Japounski or Tshipunski, where it gives form to the end of the promontory, and spreads along the bases of the higher hills sometimes with a width of a mile or more. At cape Japounski (estimating from the heights given on the charts) this plane is, in its higher parts, 700 to 800 feet above the present sealevel, but declines gradually to its seaward edge, where it is about 600 feet in height. Traces of the same or a similar plane, though at a somewhat lower level, were again seen in the immediate neighborhood of Avacha bay.

At cape Japounski this flat bordering land or narrow plateau has itself been since cut through by narrow V-shaped valleys which run from the inland hilly tract to the sea.* The excavation of the later valleys seems to have occurred while the land stood some fifty or one hundred feet below its present level, for the valleys are not cut down to the sea, but terminate seaward at such heights above the waterline. The coast cliff may be represented diagramatically thus:

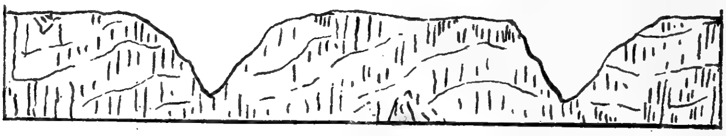

FIGURE 3.—*Diagram illustrating the Profile of the Coast Cliffs at Cape Japounski.*

That the plateau of cape Japounski is not one of deposition, but subsequently impressed, is shown by the fact that the underlying rocks are seen in the seacliffs, particularly near the extremity of the cape, to be well stratified and to be inclined at various angles, which are sometimes rather high and are entirely independent of the level contour of the

* The general appearance of cape Japounski is very well illustrated in view no. 3 on chart no. 54, U. S. Hydrographic office.

plane of denudation. These rocks may very probably be similar to those of Petrapavlovsk, but they were not examined.

Diagramatically the general structure of this part of the Kamchatka peninsula may be represented as above, but it must be understood that the illustration is not an actual drawing of any one part of the coast. The order in time of the origin of its several features, as indicated by the form of the land and with reference merely to their relative age, being as follows:

1. Stratified rocks, upturned, and denuded into systems of hills.
2. Prolonged depression of 600 to 800 feet, during which a plane of marine denudation was formed, while the sculpture of the inland hills continued.
3. Elevation of the land to within, say, one hundred feet of its present level, during which narrow valleys were cut out across the plane of marine denudation.
4. Further elevation of the land to about the present level, after which wide delta flats have been formed, as, for instance, that in the bay west of cape Japounski and that about the mouth of the Avacha river. These are so well marked as to indicate a considerable lapse of time.

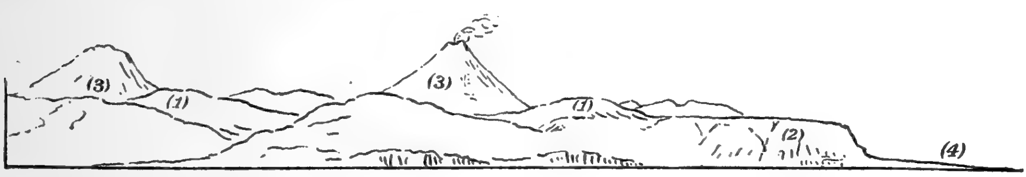


FIGURE 4.—*Diagram illustrating the orographic Characters of the southern Part of Kamchatka.*

The towering volcanic cones must, of course, have been formed at a comparatively late date in this history, and their growth has continued up to the present.

Avacha bay, entered by a narrow strait, expands within to a wide body of water from six to ten miles across. The little harbor of Petrapavlovsk is situated on the east side of the bay.

The rocks met with about this harbor are well stratified, often in regular layers a few inches only in thickness. They consist of gray, black and greenish felsites, hard argillites, generally very fine grained, associated with gray, blackish or greenish halleflinta and greenish diabase or chloritic rocks, generally schistose. All these are much indurated and considerably disturbed, sometimes, for limited areas, actually contorted. They are frequently broken by small faults, as well as by innumerable joints, cutting in all directions, so as to shatter easily under the hammer and to form by weathering rubbly slopes. While these rocks are evidently in part composed of ancient volcanic materials, they must have

been laid down in water, and date from a period much more remote than that of the existing volcanoes. They closely resemble in lithologic character some of the Paleozoic and Triassic rocks met with in British Columbia, and in their degree of alteration are like to those already noted as occurring on Attu island; but as such characters depend chiefly on the degree and nature of metamorphism to which the beds have been subjected, they afford little clew to the real age of the rocks. No trace of organic remains could be found in them.

In the vicinity of the harbor these rocks have preponderantly southerly dips at rather high angles, and a thickness of several thousand feet of them is here displayed. At the coaling place, near the entrance to the harbor on its west side, they dip south 10° east (magnetic) at an angle of 30°, and similar dips are found along all this side of the harbor. About a mile outside the harbor, on the east shore of Avacha bay, similar rocks are seen in low cliffs, dipping south 40° west (magnetic) at an angle of 60°; but in following the shore into the harbor varied and irregular dips are met with. Further out, beyond a deep indentation in Avacha bay, the stratification in some of the cliffs appears to be nearly horizontal.

Mr Collie, in the Zoölogy of Captain Beechey's Voyage, notes the occurrence of serpentine as a frequent constituent of the older rocks about Avacha bay. These rocks, as represented in the immediate vicinity of Petrapavlovsk, he refers to in a general manner as clay-slates.*

On the east side of the harbor of Petrapavlovsk, behind the village, a distinct, though faintly impressed line running along the hill, seems to indicate the existence of an old sea-margin at a height of about 250 feet above the present, but apart from this no evidences of terracing were observed at this place. Neither were any erratics or bowlder-clay met with; nor were any striated rock-surfaces or other evidences of glaciation anywhere seen. So far as they go, such observations are, of course, entirely negative in character; but it may be affirmed that no traces of the Glacial period, such as those so commonly found on the coast of British Columbia and that of southeastern Alaska, are here apparent.

## Pribilof Islands.

Mr. J. Stanley-Brown, of the United States Geological Survey, during his residence upon these islands in 1891, made a thorough examination and survey of them. The main results of his work are given in brief in a paper lately read before the Geological Society of America.† Mr

* Zoölogy of Captain Beechey's Voyage, London, 1839, p. 167.
† Bull. Geol. Soc. Am., vol. iii, p. 496.

Stanley-Brown found the islands to be entirely volcanic, and for the most part basaltic. The centers of eruption are still recognizable, and the date of origin of the accumulations is regarded as post-Pliocene. No erratics are found upon the higher levels and there are no traces of glaciation either general or local. Raised beaches were not observed, except in one instance which is believed to be due to local volcanic disturbance. The island of Saint George has been consideraly affected by orographic movement since its formation, but that of Saint Paul is believed to have remained unchanged.

Though several visits were made to these islands during the summer of 1891, my opportunities for geological observations there were very small as compared with those of Mr Stanley-Brown and the facts noted therefore require the briefest mention only.

The most interesting locality on either island is undoubtedly that of Black bluff, Saint Paul island, where fossils have been collected by Wassressenski, Elliott and others as well as by Mr Stanley-Brown. I had the pleasure of visiting this place with the last named gentleman, and entirely concur with his view as to the mode of occurrence of the fossils, namely, that they are found only in detached fragments of calcareous argillite which are included in a deposit of basaltic scoria and volcanic ash.* The distinctly bedded character of this enclosing rock, however, leads me to believe that it was laid down under water, the products of the volcanic eruption being there mingled with fragments ripped up from the sea-bed by the same force. If this view be correct, it follows that the island, or this part of it at least, has been elevated by an amount of at least 80 feet since the time of the eruption.

The manner in which the fossils occur at this place shows that they cannot be accepted as fixing the precise age of the formation, but only as representing some beds which already existed at that time. Thus the fact that all the molluscs collected here by Mr Stanley-Brown are still living species, while earlier collections included some species now extinct, presents no difficulty.† It tends merely to show that deposits due to the upper Miocene (Astoria group of Dall), with others to which a post-Pliocene date must be attributed, occur in the bed of this part of Bering sea, and to confirm the later post-Pliocene date accorded to eruptions which have produced the islands.

Another fact which seems to show that the island of Saint Paul must have been upraised to some extent since the date of the period of vulcanism is the difference of contour which exists between the higher hills of the island and the sometimes widely extended lower slopes attaching

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* Op. cit., p. 497.

† Op. cit., p. 498. Bull. U. S. Geol. Survey, no. 84, pp. 257, 258.

to them. The profile of the southern side of the island as seen from Northeast point may be specially instanced. Here, from the steep slope of Polovina hill, a very gently inclined plain extends seaward to the edge of the low modern seacliffs which now border the actual shore. This flat tract is covered with scoriaceous materials. Its highest part is at an elevation of about 100 feet above the present sealevel, and its existence appeared to me to be most easily explained by supposing that the volcanic ejecta were here distributed and levelled as they fell in a shallow sea. An examination of Mr Stanley-Brown's contoured map of the island * will show that (apart from seacliffs) the slopes below the 100-foot contour line are throughout notably light, while those above it are nearly all much steeper.†

On the low flat land of the Northeast point of Saint Paul island, the bones of whales and walrus are found in considerable abundance imbedded in sandy deposits. These lie at a height of some feet above the highest level of modern storm-wash.

As it is impossible that the remains of whales, at least, could have been carried to their present position otherwise than by the sea (the island having been uninhabited till the time of its discovery by the Russians, about 100 years ago), it appears to be certain that the land has been further raised within quite recent times by an amount sufficient to account for their presence—say, about ten feet. Evidence to the same effect is also found in this vicinity in the wide flat to the west of Hutchinson hill, where the superficial sandy deposits have at some former time been stripped away by the sea, leaving a bowlder-strewn tract which is bounded on the inland side by a low step or rise.

In his account of the Pribilof islands (page 499) Mr Stanley-Brown writes as follows :

> "There are two fragments of paleontologic evidence connected with these islands which, as they have been used by writers, demand a cautionary word. The tusk of a mammoth was found in the sands of Northeast point on Saint Paul island, and the tooth of one is reported as coming from the shores of Saint George. As there is not a foot of earth upon either island, save that which has resulted from the decomposition of the native rock and the decay of the vegetation, the value of such testimony is questionable."

Dall attributes more importance to these discoveries, and authenticates that on Saint George on the evidence of Veniaminof,‡ while he also quotes Stein as an authority for the occurrence of similar remains on

* Fur-seal Arbitration: Case of the United States, map no. 2.

† It is, however, to be remembered that Mr Stanley-Brown's examination of the island led him to refer the differences here commented on to other causes, which may possibly afford a sufficient explanation of them.

‡ Op. cit., p. 266.

Unalaska island. It will be observed that Mr Stanley-Brown does not question the finding of the mammoth remains on the Pribilof islands, and I do not attach the same significance to the absence of extraneous earthy matter in the soil to which he refers. This, in fact, appears to afford further reason to believe that the bones could not have been carried thither in any adventitious manner, and to render it as nearly as possible certain that the animals to which they belonged must have found their way to the islands at a time when they were connected with the American continent by means of a wide plain, such as Mr Stanley-Brown himself explains in one of the paragraphs of his paper,† would be made if an elevation of 200 feet should now take place in Bering sea.

The absence of old sea-margins on the Pribilof islands may be accepted as showing that since the time of their original elevation above the sea they have not been again submerged, but there is no evidence whatever to show that they may not have stood at higher levels.

My observations agree with those of Mr Stanley-Brown in regard to the absence of erratics above the present sea-margin, but it may be added that not infrequent pebbles and small bowlders of granitic rocks occur upon the actual beaches in association with local débris. These have in all probability been brought hither either by the floe-ice, which fills this part of Bering sea in winter, or attached to the roots of drift tree-trunks, which are often washed ashore.

## Nunivak Island.

The form of Nunivak island is very imperfectly represented on the charts. It was approached by us on the 7th of August on its south-western side, where a landing was effected. On the following day the western and northern shores were coasted at a distance as small as appeared to be compatible with safety, and the next night was spent at anchor in Eteolin harbor, at the northeastern extremity of the island.

The island is throughout grass-covered, but entirely devoid of trees, though a few stunted shrubs are found in some of the valleys. Its coasts are usually rather low, but vertical cliffs of 100 to 150 feet in height appear at the points and projecting headlands, while shelving rocky shores, with occasional sandbeaches and sanddunes, characterize the various open bays. The cliffs show several superposed and horizontal layers of basaltic rock, and in the low hills of the interior of the island similar but overlying massive flows of the same kind may be traced. These hills are all more or less plateau-like in form, and might readily be mistaken in some places for old marine terraces. The highest

* Op. cit., p. 496.

parts of the island were estimated at about 500 feet. At Eteolin harbor the rock is a gray olivine-diabase, very porous and cellular, and separated into layers which similate horizontal bedding, but which are due to flow structure.

Part of the east coast of the island was subsequently seen from a distance, and its appearance is so similar to that of the other coasts that there can be little doubt that the island is entirely composed of nearly horizontal basaltic flows. The basalts examined are all fresh looking and unaltered, like those of Saint Paul island. The much altered sandstones reported by Dall at Eteolin harbor were not found, nor was I able to identify any volcanic cones upon this island.*

No erratics or traces of glaciation were observed on the parts of Nunivak island visited.

## Cape Vancouver.

Cape Vancouver, twenty-five miles distant from the eastern coast of Nunivak island, is a projecting point of Nelson island, which is to all intents a portion of the adjacent Alaskan mainland. It is a bold and high promontory, which, though scarcely to be characterized as mountainous, rises to a height of probably 1,000 or 1,500 feet. It evidently forms one of several or many projections of higher land along this part of the Alaskan coast, which are connected by broad, low, level tracts. The north shore of the cape, which alone was examined, forms scarped bluffs or cliffs, rising from the edge of the sea, and presenting fine exposures of sandstones and sandy shales, well bedded and dipping southward, at low and undulating angles. At the extremity of the cape these beds appeared to be horizontal, and on the south side, though imperfectly seen from a distance, they seem to lie at higher and more irregular inclinations.

The sandstones, where examined, are gray, bluish and brownish in color, rather soft, and sometimes nodular. They contain a few very thin and dirty seams of coal or lignite, of which the thickest seen was only a few inches. There are also in the sandstones numerous carbonaceous fragments and occasional fossil leaves, of which a couple were collected. These have been submitted to Sir J. William Dawson, who supplies the following note upon them:

"No. 1. *Juglans acuminata*, R. Braun, Heer, Flora Fossilis Alaskana, 1869, page 38. *Ib.*, Flora Fossilis Arctica, vol. I. *Ib.*, Contributions to Fossil Flora of N. Greenland. Trans. Royal Society, 1869.

"This species is stated by Heer to occur in sandstone at English bay, Alaska. It is also found at Atanekerdluk in Greenland, and is said to occur in the European

* Cf. Dall, op. cit., p. 245.

Miocene at Oeningen and Hohe Blunen. Very similar species, if not mere varietal forms, are credited by Lesquereux and Ward to the Laramie and Tertiary of western America. The plants found with this species at English bay, Alaska, and at Atanekerdluk, Greenland, are closely allied to those of the upper Laramie of Canada, and I have been inclined to refer them to this age rather than to the Miocene.

"No. 2. Fragment of a leaf of considerable size, but too imperfect for determination. It may possibly have belonged to a species of *Quercus* or of a large *Corylus*, like *C. McQuarrii*, but this is quite uncertain."

According to the classification adopted by Dr Dall in his recent work, the beds at cape Vancouver would appear to fall under the Kenai group of the Miocene, though the locality is a new one.*

Upon the beach at cape Vancouver fragments of vesicular basalt are abundant, and the distant outline of the cape led me to suppose that the stratified rocks are capped by basaltic flows in the higher hills a short distance inland from the extremity of the cape.

A fairly distinct though rather narrow terrace of earthy materials was observed along the north shore of the cape at a height of 80 to 100 feet above the sea.

## Saint Matthew, Hall and Pinnacle Islands.

Saint Matthew island, with Hall and Pinnacle islands near it, are situated in the center of the northern part of Bering sea. They are so remote from any other land that they appear never to have been reached by the Eskimo, though polar bears are brought to them on the floe-ice of winter and remain during the summer. Saint Matthew island itself is long and narrow, extending in a northwest by southeast direction for about thirty miles. Hall island, some five miles in greatest length, lies near the northwest end of Saint Matthew, and Pinnacle island is situated at a distance of six or seven miles to the south of the main islands. The islands are very imperfectly delineated on the existing charts.

Saint Matthew island may be described as consisting of the unsubmerged portion of a range of bold rounded hills, some parts of which probably reach an elevation of about 1,500 feet. It is in reality formed of three isolated groups of hills of unequal size which may originally have been separated by narrow straits, but are now united by tracts of low gravelly land washed up by the action of the sea. These low lands include several lagoons, into which streams fall and from which the water percolates through the gravel to the sea. Hall island is in every way similar to Saint Matthew, but happens to be divided from it by a still existing strait.

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* Op. cit., p. 234.

The forms of the hills are not rugged or scarped, but they have been cut back into seacliffs of varying height along all the shores.

There is no appearance of volcanic craters, cones or centers of eruption, nor were any volcanic rocks of surface origin, such as the basalts of the Pribilof and Nunivak islands, seen about these islands. The hills seem to be the residual portions of much more extensive volcanic accumulations of some antiquity, of which the greater part has been removed by ordinary processes of denudation. So far as examined, they were found to be composed of rocks generally less basic in composition than the basalts and probably in the main of deep seated origin, but nevertheless entirely volcanic or eruptive. No raised beaches or terraces were observed, nor were any recognizable instances of travelled bowlders or traces of glaciated rock surfaces seen on the islands of this group.

The following more detailed notes include the results of examinations made on August 10, 11 and 12, 1891:

The cliffs at cape Upright, the eastern end of Saint Matthew island, are in some places about 500 feet in height, very rugged in form and tenanted by numerous seabirds. The sea has here cut back beyond the crests of a small group of hills, so that the ground slopes away steeply inland from the summit of the cliffs. The rocks are everywhere very much shattered and jointed. They consist of greenish and purplish feldspathic materials, often porphyritic, in many cases evidently clastic, and in one place including a hard, pale greenish tuff. These are associated with a gray fragmental rock chiefly composed of granitic material, with much epidote and chlorite. This simulates a granite, but contains also angular fragments of the darker porphyrites. Nearly all these rocks are considerably decomposed, and resemble rocks met with in British Columbia, where the centers of eruption of Miocene date have been cut through or exposed by denudation.

In following the north coast of Saint Matthew island from cape Upright to its deepest indentation, which forms an open bay, where we anchored, a stretch of low land with gravel beach is first passed. Cliffs then border the sea, and are composed of rather massive rocks of dark color, resembling those above described. In rounding the most prominent point between cape Upright and the bay, however, a thick stratum of a grayish yellow color is observed in the cliff. This rests with perfect regularity on the darker rocks below, but its upper surface appears to have been plowed up by the passage over it of the overlying material in a molten state. The general dip of the beds is southward at an angle of about 15°. The light colored material is probably tuff or fine volcanic agglomerate.

From the anchorage westward, the rocks of the north shore of Saint Matthew island were seen only from the sea. They appeared to be

similar to those last described, and are very probably of about the same horizon throughout. The pale colored stratum referred to reappears at several places, and always with a low southerly dip away from the sea.

The south side of Saint Matthew island was clearly seen from the sea and closely examined through the telescope westward to about abreast of Pinnacle island. Its general features and the appearance of its rocks are in every way similar to those of the north side.

The general structure of Hall island, in which the same rocks are continued, is illustrated by the subjoined diagram, sketched along its east coast.

The principal dip is here to the northward at low angles, and the rocks consist of a series of "porphyrites," with intercalated tuffaceous and agglomeritic beds. The rocks shown at $a$, $d$ and $f$ in the diagram, consist preponderantly of grayish purple, purple and gray porphyrites, nearly massive, but sometimes with a rude, irregular, columnar structure, particularly toward the north end of the island, where the rock is distinctly an augite-porphyrite. They have been considerably altered and

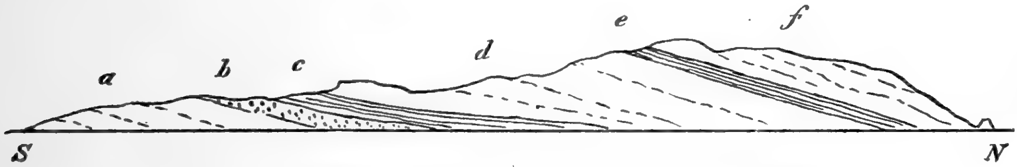



FIGURE 5.—*Diagramatic Section along the east Coast of Hall Island.*

decomposed, frequently largely silicified by subsequent solfataric action, while they are often markedly rusty in irregular bands. *C* 'and *e* are pale gray in color, and consist of tuff, volcanic ash or fine agglomerate, which is evidently water-bedded, and in some places rather finely stratified. This is particularly the case in respect to the bed *c*, which is from 200 to 300 feet thick, and is underlain by a similar thickness (*b*) of coarse brownish and blackish agglomerate, holding some fragments from one to three yards in diameter.

The section evidently represents the results of volcanic action which has been in part or altogether submarine. The rocks are everywhere much fractured and jointed, giving rise under the action of the sea to bold, rugged and picturesque cliffs like those of cape Upright. Much chalcedony and jasper occur on the east side of Hall island near its southern end in the porphyritic rocks, and these minerals here compose a considerable portion of the worn beach pebbles in some places. The chalcedony is generally white or milky, the jasper red or red veined with yellow.

In 1791 Sauer, of Billing's Russian Scientific Expedition, landed on

this island, probably near this place, and particularly notes the abundance of jasper and chalcedony.*

Pinnacle island was so named by Cook in 1778. It is a narrow crest of jagged rocks, apparently about a mile in length and lying north and south. On some charts its height is given at 900 feet, and its higher parts may reach this elevation, but as its form is very imperfectly shown on the charts no accuracy can be attached to the height stated. It presents a series of vertical and sometimes overhanging cliffs to the sea on both sides, gashed by transverse breaks into a series of narrow peaks and pinnacles. In many places the sea washes the base of sheer cliffs which often show low caves along the water line. Elsewhere rough narrow beaches permit a landing to be made in calm weather.

Myriads of birds find nesting places in the cliffs. Several polar bears were also observed on the island, and on a low neighboring rock to the southeast a considerable colony of sealions was noticed.

Some hours were spent about the island under favorable circumstances of weather on August 12, and the shore was closely followed all round in the steam launch of H. M. S. *Pheasant*.

The rocks are everywhere very similar to those of cape Upright, and evidently belong throughout to the same old volcanic series.† Like these, they are very much shattered and disturbed. Dark purplish and greenish feldspathic rocks, which are often distinctly stratified or stratiform and dip at various angles, are perhaps the most abundant. Some beds of gray arkose material, like that of cape Upright, were also seen here. These are now consolidated into a hard rock, but occasionally show very distinct stratification. The granitic débris is here embedded in a chloritic matrix.

## Saint Lawrence Island.

Saint Lawrence island, the largest in Bering sea, is about 85 miles in length, and is situated not far to the south of Bering strait. The western end of this island was coasted from Southwest point to cape Chibukak. Between Southwest point and cape Sanachno the shore is formed by rugged cliffs several hundred feet in height, with some outlying rocks and reefs. These cliffs are composed for the most part of a gray rock, which from its massive appearance, as well as from the observations subsequently made at cape Chibukak, is almost certainly granitic. This is seen to be overlain, where higher ground approaches the shores, by hori-

* An Account of a Geographical and Astronomical Expedition to the northern Parts of Russia. London, 1802, p. 235.

† The statement that Pinnacle island is a "volcanic chimney, still smoking" is incorrect. Bull. U. S. Geol. Survey, no. 84, p. 258.

zontal or very lightly inclined stratified materials of brownish and reddish brown colors, which are with little doubt volcanic, but more probably scoriaceous or agglomeritic than basaltic. Low plateau-like hills some miles further inland appear to be composed of similar materials. Higher hills, at a greater distance from this part of the shore, were seen only very imperfectly, between clouds.

The northeast point of the island, ending in cape Chibukak, consists of a plateau about 200 feet in height, with a notably level outline as seen from the sea. This plateau, however, declines to the southward to lower land, by which it is connected with the rest of the island. It breaks

FIGURE 6.—*Shattered granitic Rocks, Cape Chibukak, Saint Lawrence Island.*

off to seaward in cliffs or steep rocky slopes, with here and there projecting pinnacles of fissured rock rising from them.

A landing was made on the east side of cape Chibukak, where the plateau was found to consist of gray biotite-granite of uniform color and texture and moderately coarse grain. The surface of the plateau is everywhere covered with irregular, angular, broken blocks of granite, much like those often found on high mountain summits, and doubtless the result of severe climatic conditions acting upon the naturally jointed rocks. No erratics were found upon the plateau nor any traces of glacial striation or smoothing, though if such at any time existed they may

have been lost in consequence of the breaking up of the original rocky surface. The impression conveyed was, however, that this condition of the surface was of ancient date and had been preserved because of the exemption of the region from the effect of glaciating agents. Some stones were found on the present beach which did not appear to belong to the actual vicinity, but if transported from any distance the abundance of floe-ice known to occur in these seas in winter is quite sufficient to account for this. Nothing whatever was found to favor the theory of an "oversweeping glacier," the supposed action of which has been particularly illustrated by Mr John Muir from the contours of hills and cliffs on this island.*

The level contour of the plateau suggests that it may represent an ancient plane of marine denudation or peneplain. On the east side of the cape a fairly distinct terrace occurs at a height of about fifty feet above the sea. This has been cut back in the granitic rocks as a narrow step, which is now encumbered with broken blocks from the old sea-cliff above.

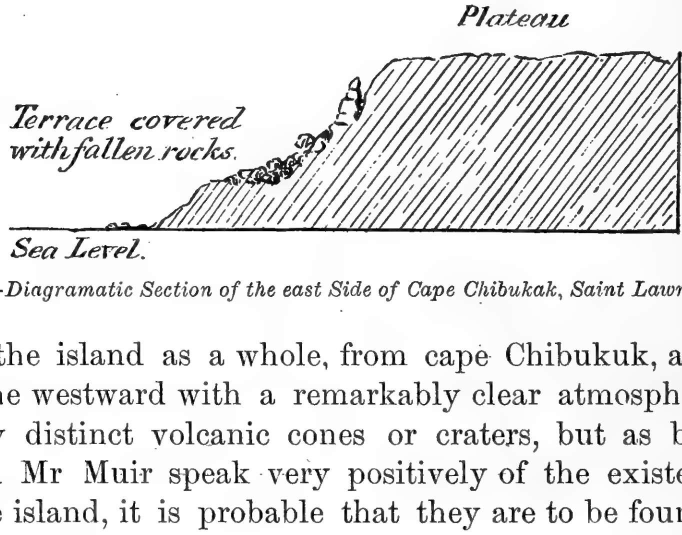



FIGURE 7.—*Diagramatic Section of the east Side of Cape Chibukak, Saint Lawrence Island.*

Views of the island as a whole, from cape Chibukuk, and also from the sea to the westward with a remarkably clear atmosphere, failed to disclose any distinct volcanic cones or craters, but as both Captain Hooper and Mr Muir speak very positively of the existence of such cones on the island, it is probable that they are to be found in its central or eastern parts.†

The surface of the island, so far as seen, consists wholly of barren moorland, with grass and moss and often rock. There are no trees, and large masses of snow were found in some places along the bases of the cliffs and down to the level of the sea.

## Plover Bay.

From Saint Lawrence island we crossed to the Siberian coast at Plover bay, so named because H. M. S. *Plover*, Captain Moore, wintered there

* Report of the cruise of the Corwin, 1881, pp. 137–140.

† Ibid., pp. 33, 140.

in 1848–'49, in connection with the Franklin search. It is situated in latitude 64° 30′, and indents the southern part of the promontory separating Anadir bay from Bering strait. The weather was such as to give us while approaching it a good view of a long stretch of this part of the Siberian coast. The outlines of this coast are everywhere bold and mountainous, though none of the highest points in sight probably exceed 4,000 feet in elevation. It is entirely bare and treeless, brownish or gray, showing only here and there in the valleys the green color of herbage.

Fiord-like inlets, and narrow straits of the same nature, characterize this part of the coast, but they are on a small scale as compared with those of British Columbia and southeastern Alaska. Soundings given on the charts show that the water in these inlets and channels is deeper than that about their mouths, but the greatest depth actually recorded appears to be about 50 fathoms.*

Plover bay is one of these small fiords, surrounded by steep, rocky mountains, notably covered everywhere on their slopes with talus material, consisting of broken angular rock, through which spires and crags of solid rock often project, especially on the sides facing the sea. Generally speaking, the mountains show ordinary denudation forms, with wide buttress-like projections and intervening steep valleys and ravines; the shapes assumed resembling those commonly met with where the rocks are so much shattered and jointed as to crumble away under the weather with almost equal facility in any direction. The ranges end along the coast in capes terminated by seacliffs. On the whole, the most peculiar feature is the great abundance of loose angular material. It is doubtful to what extent this may be directly referred to rapid disintegration due to the subarctic climate of the climate, or in how far it may be accepted as evidence of prolonged weathering uninterrupted by glaciating agents.

From cape Tchalpin (Indian point) to cape Nismenni, and thence as far as cape Tchukotski, the rocks as seen from the sea are generally gray in color and are in all probability granitic. Between the range ending seaward at cape Tchukotski and the valley containing lake Moore of the chart is a smaller range composed near the sea of similar gray rocks, but about two miles inland assuming brownish and reddish colors. Brownish and reddish weathering rocks also compose most of the next range, which separates lake Moore from Plover bay and includes mount Slavianka. From what was afterward seen in Plover bay, this difference of coloration may not indicate any essential change in composition.

* Dall, however, speaks of a depth of over 100 fathoms having been obtained in the center of Plover bay. Alaska and its Resources, pp. 465, 512.

Bold Head, which forms the seaward end of the range last referred to, shows in its cliffs several well marked intrusive dikes, weathering yellowish and blackish.

The whole west side of Plover bay, as well as the outer coast beyond it for several miles, consists of gray rocks which are likewise probably granitic.

The only locality in which the rocks were actually examined in this region, in the short time available, was the east side of Plover bay between port Providence and Emma harbor. They are here, in the main, rather coarse grained, gray biotite-granite, much like that of the west end of Saint Lawrence island, but in places passing into a hornblendic granite. There is also, however, a considerable proportion of gray and reddish porphyritic rock, resembling a mica-syenite or minette, which is probably later in date than the granite and intrusive in it. No strictly volcanic rocks of any kind were seen in this vicinity, nor were any stratified rocks observed.

The general description of this part of the Siberian coast above given will show that superficial earthy deposits are not abundant, but there are in the vicinity of Plover bay some deposits of this kind which attracted special attention.

The point on the outer coast immediately east of the valley of lake Moore, terminates in an apron-like flat of land which breaks off seaward in a low cliff, apparently formed of hard clay, weathering to a fawn-color and thickly studded with large bowlders which lie more or less definitely in regular lines, giving a stratified appearance to the whole. Material of the same kind is preserved in the angle of the next bay nearest to Bold Head. It was also seen from a distance to form the coast along the bottom of the bay into which Reindeer river flows, on the opposite side of the entrance of Plover bay, and again occurs in two places on Emma harbor on the west side, a little within the entrance to the harbor and at its southern bay.

The last named locality was the only one actually examined on the ground. The deposit is here bluish gray where freshly exposed, and is a rather hard clay with a considerable proportion of coarse sand and gravel, containing many bowlders of somewhat varied lithologic character. These are subangular in form, but none were found which actually showed glacial scratching, neither were any shells found in the mass. The deposit, nevertheless, undoubtedly represents a species of bowlder-clay. It does not anywhere take the form of definite terraces, but as it is nowhere seen, or at least not in any considerable mass, at a greater height than about 200 feet above the sea, while it is occasionally rather wide spread below this level, it may be assumed as a whole to

represent an approximate terrace-level, having relation to a former depression of the land of about the amount stated.

In Plover bay, on August 16, large masses of snow occupied many of the hollows, sometimes quite down to the edge of the sea. Portions of these accumulations undoubtedly last throughout the summer. No glaciated rock surfaces were actually observed, but this negative evidence is here of small value, as it depends upon observations made in a very short time and over a very small area. Mr Muir speaks of having found glaciated rock surfaces in Plover bay, and pictures it as having been at one time filled by a glacier thirty miles in length and from 2,000 to 3,000 feet in thickness.*

## General Remarks.

Bering sea is a dependency of the north Pacific, marked off from it by a bordering chain of islands like those which outline Okhotsk sea and the sea of Japan. It differs from these two seas by reason of its connection to the north with the Arctic ocean, and in the fact that while the whole eastern part of its extent is comparatively shallow, the profounder depths of the north Pacific (in continuation of the Tuscarora deep) are continued into its western part. The Aleutian islands, regarded as a line of demarkation between the main ocean and Bering sea, are analogous to the Kurile islands with Kamchatka, and to the islands of Japan. As to the Commander islands, though these appear to lie in the continuation of the arc formed by the Aleutians, they are separated by a wide and, so far as known, very deep stretch of ocean from the last of these islands, and it is wholly probable that they may represent an altogether independent local elevation analogous to that to which Saint Matthew and its adjacent islands are due.

The western part of Bering sea has as yet been very imperfectly explored with the deep-sea lead, but the following general facts may be gathered from the existing charts: The entire chain of the Aleutian islands is bordered at no great distance to the south by abyssal depths of the Pacific. The whole western portion of the chain likewise slopes rapidly down on the northern side into very deep water, exceeding 1,000 fathoms as far to the eastward as Unimak island; but from the vicinity of Unimak pass (longitude 165° west) the depths to the north of the islands are consistently less than 100 fathoms. Beginning near the Unimak pass, the edge of the hundred-fathom bank runs northwestward, passing to the west of the Pribilofs and Saint Matthew island and meeting the Asiatic coast in the vicinity of cape Navarin, in about north latitude 60°. Thus all parts of Bering sea to the north and east of this line, together

* Report of the Cruise of the Corwin, 1881, p. 143.

with Bering straits and much of the Arctic ocean beyond, must be considered physiographically as belonging to the continental plateau region and as distinct from that of the ocean basin proper, and there is every reason to suppose that it has in later geologic times more than once and perhaps during prolonged periods existed as a wide terrestrial plain connecting North America with Asia.

In all probability this portion of the continental plateau is a feature much more ancient than the mountain range of which the outstanding parts now form the Aleutian islands. This range, though to some extent due to uplift, as for instance in the case of Attu island, is chiefly built up of volcanic materials. Its eastern part, in the Alaskan peninsula and as far as the Unimak pass, must be regarded as having been built upon the edge of the old continental plateau. Its western part, though certainly the continuation of the same line of vulcanism, runs off the edge of the plateau and rises directly from the ocean-bed.

The available evidence goes to show that the submarine plateau of the eastern part of Bering sea, together with much of the flat land of western Alaska, was covered by a shallow sea during at least the later part of the Miocene period, while the most recent period at which this plateau stood out as land is probably that at which, according to facts previously noted, the mammoth reached the Pribilof islands and Unalaska island across it.

As to the date of the formation of the Aleutian chain, Dall inclines to the belief that it marks a line of weakness or faulting which has been in course of development since early Mesozoic times.* This may be the case, but I have found nothing on record nor have I myself met with any facts which appear to require so early a date of origin. The association of the volcanic materials of the islands in some cases with Miocene marine fossils and with plant-remains, noted by Dall, shows that early in that period, or possibly before it, the islands existed in some form, for the organic remains are those of shores and shallow water, not of the deep sea. The existence of very ancient volcanic products forming well bedded rocks on Attu island, and perhaps elsewhere in its vicinity, does not appear to have any necessary connection with the date of the vulcanism to which the islands as a whole are referable, for such rocks are very common in formations of many periods on both sides of the Pacific, and may be due to volcanic action along lines entirely distinct from that now occupied by the Aleutians and long since extinct. We may therefore, I believe, assume that the building of the Aleutian islands began in the later Eocene or earlier Miocene, that it was continued with vigor throughout the Miocene, and in an intermittent and declining way has survived up to the present time.

* Op. cit., p. 242.

The evident marks of prolonged subaërial denudation which exist on all the islands of this chain which I have seen, appear further to show that it has been long exposed to such action since the main period of its formation; that as a rule it has stood unsubmerged since the Miocene, and that though it may at some period have been more elevated, it has either not been more deeply submerged than it is at present, as, if so, that such submergence has endured for a comparatively very brief period.

Saint Matthew and its adjacent islands, with the Commander islands, appear to have much the same history with the Aleutians, and may very well have been coeval with them in origin. The later eruptions, to which the Pribilof islands and Nunivak island are due, have doubtless also left their traces in the Aleutian chain, while the volcanoes of Kamchatka may have originated at this later period and have continued their activity with little relaxation to the present time.

The planes of marine denudation, noted particularly at Saint Lawrence island and at cape Japounski, on or near the western border of Bering sea, seem to require prolonged stability at a level some hundreds of feet lower than the present in that part of the region, and the fact that this plane appears to be capped by volcanic rocks at Saint Lawrence island (particularly if no evidence of existing volcanoes is found there), makes the date of this submergence somewhat remote. It may be conjectured that it corresponds with the general submergence of the later Miocene. That the amount of such submergence should vary in different localities is quite in accord with what might be expected, perhaps, in any region, certainly in one in which volcanic forces of a local kind have to be allowed for.

The difference of climate which would result in the northwestern part of North America from the closing of Bering strait and the addition of the shallow eastern part of Bering sea to the continental land may not have been very great, inasmuch as the strait is even now a shallow one and no very great volume of abnormally cold or warm water flows through it in either direction. The effect would be to slightly lower the temperature and decrease the precipitation on the adjacent lands. Evidence has, however, recently been obtained of a much more important factor in regard to late changes of climate in this region, in the observations of Mr I. C. Russell, which show that the great mountain range of the Saint Elias alps must have been entirely formed in Pliocene or post-Pliocene times.* The crumpling and upheaval of the beds which now form this range must have relieved a notable and accumulating tangential pressure of the earth's crust, the result of which it is yet difficult to trace; but that it must have brought about extensive changes of level

* National Geographic Magazine, Washington, p. 174. Bull. U. S. Geol. Surv., no. 84, p. 259.

throughout the region over which this pressure was exerted seems certain, and I am inclined to suppose that it may have had much to do with the great later Pliocene uplift and subsequent depression to which the British Columbian region appears to have been subjected.*

One of the most remarkable features connected with the Bering sea region is the entire absence of any traces of a general glaciation. Statements to the effect that Alaska, as a whole, showed no such traces were early made by Dall † and concurred in by Whitney. The result of my later investigations in British Columbia and along the adjacent coasts have been to show that such original statements were altogether too wide; that a great Cordilleran glacier did exist in the western part of the continent, but that it formed no part of any hypothetical polar ice-cap, and that large portions of northwest America lay beyond its borders.‡

Statements made by Mr John Muir, in which he not only attributed every physical feature noted by him in Bering sea to the action of glaciation, but even expressed the opinion that Bering sea and strait represented a hollow produced by glaciation, § remain altogether unsupported. It might be unnecessary even to refer to them but for the fact that they relate to a region for which the data on this subject from other sources are so small. No traces have been found of general glaciation by land ice in the region surrounding Bering sea, while the absence of erratics above the actual sealine show that it was never submerged for any length of time below ice-encumbered waters.

These facts, moreover, connect themselves with similar ones relating to the northern parts of Siberia in a manner which will be at once obvious to any student of the glacial period.

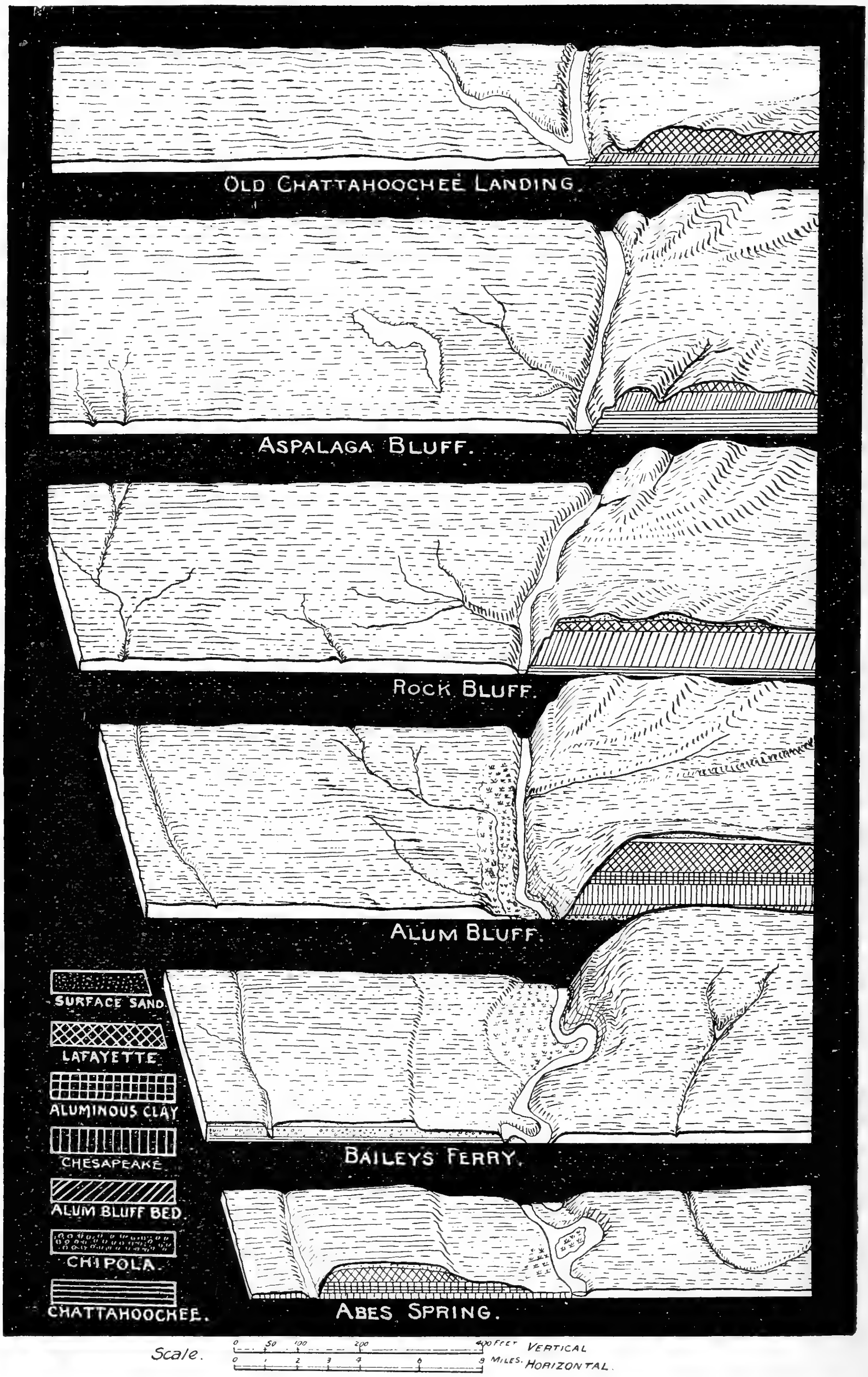
Respecting the latest changes in elevation of the land, it may be stated that in several widely separated places there is evidence of a recent slight general uplift. This was noted at Unalaska, Attu, Bering island, Saint Paul island and Saint Matthew island, but the amount of elevation indicated is small, being in fact from 10 to 30 feet only.

* Trans. Royal Soc. Canada, vol. vii, sec. iv, p. 54.

† Alaska Coast Pilot, 1869, pp. 195, 196; Alaska and its Resources, pp. 460, 461.

‡ Quart. Journ. Geol. Soc., vol. xxxiv, p. 119; vol. xxxvii, p. 283; Report of Progress, Geol Surv. Can., 1877–'78, pp. 136 B, 151 B; Trans. Royal Soc. Canada, vol. vii, sec. iv, plate ii, map 4.

§ Report of the Cruise of the Corwin, 1881, p. 147.




STEREOGRAPHIC MAP OF AREA ALONG APALACHICOLA RIVER
FROM OLD CHATTAHOOCHEE LANDING TO BLOUNTSTOWN.

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# CENOZOIC GEOLOGY ALONG THE APALACHICOLA RIVER*

BY WILLIAM H. DALL AND JOSEPH STANLEY-BROWN

(*Read before the Society December 27, 1893*)

## CONTENTS



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## Introduction.

The most complete series of Neozoic rocks in continuous succession which has yet been observed on the Gulf coast is that which is exhibited in the natural sections exposed in the bluffs of the Flint and Apalachicola rivers, in southwestern Georgia and western Florida. For this reason the series has been adopted in various publications * as a standard by which to correlate the different Neocene beds of this general region. The longest continuous series of beds in one section is exposed at Alum bluff, in township 8, range 1 north, section 24, Liberty county, Florida. Attention was first called to this series by Mr D. W. Langdon in 1889,† from observations made two years earlier. At the suggestion of Mr T. H. Aldrich, who had identified Langdon's fossils, and, in coöperation with him, Mr Frank Burns, of the United States Geological Survey, was sent to Alum bluff in 1890, and a collection and section made by him were sent in. This section, in which the heights were determined with a pocket aneroid by Mr L. C. Johnson, who visited the bluff when Mr Burns was at work, was printed on page 113 of Bulletin 84, already referred to. In December, 1891, under the instructions of Mr George H. Eldridge, Alum bluff was visited by a party, including Messrs L. C. Johnson and Edmund Jussen, from whom separate reports and sections are on file in the archives of the United States Geological Survey. Subsequently Dr J. W. Spencer with a party, and Professor Raphael Pumpelly, assisted by Mr A. F. Foerste, examined this locality. A valuable paper by the latter gentleman has recently appeared‡ and Professor Pumpelly has published§ additional data establishing an unconformity at the base of the Neocene in this series.

In the above enumeration only those visitors through whom information about Alum bluff has reached the writers of this paper are referred to, though several other observers are believed to have visited the locality.

The importance of the Apalachicola section for southern geology is manifest, and the fact that there were serious discrepancies between the various accounts of it hitherto accessible, not only concerning the succession of the beds and their exact nature, but even in regard to so simple a matter as the height of the bluff, decided the writers of this paper, with the approval of the Director of the United States Geological Survey, to reëxamine the subject on the spot. Previous observations

* Bulletin 84 (Neocene), U. S. Geological Survey, 1891. Transactions Wagner Free Inst. Sci. vol. 3, 1890–'92, etc.

† Am. Jour. Sci., third series, vol. 38, p. 324.

‡ Studies on the Chipola Miocene, Am. Jour. Sci., vol. 46, October, 1893, pp. 244–54.

§ Am. Jour. Sci., vol. 46, December, 1893, pp. 445–447.

placed the total thickness of the strata above water at Alum bluff, at low stages of the river, at 63 feet, others at 125 feet. The earlier observers regarded the clay above the Chesapeake marl as lignitic, which led to its correlation with other lignitic beds to which attention has been

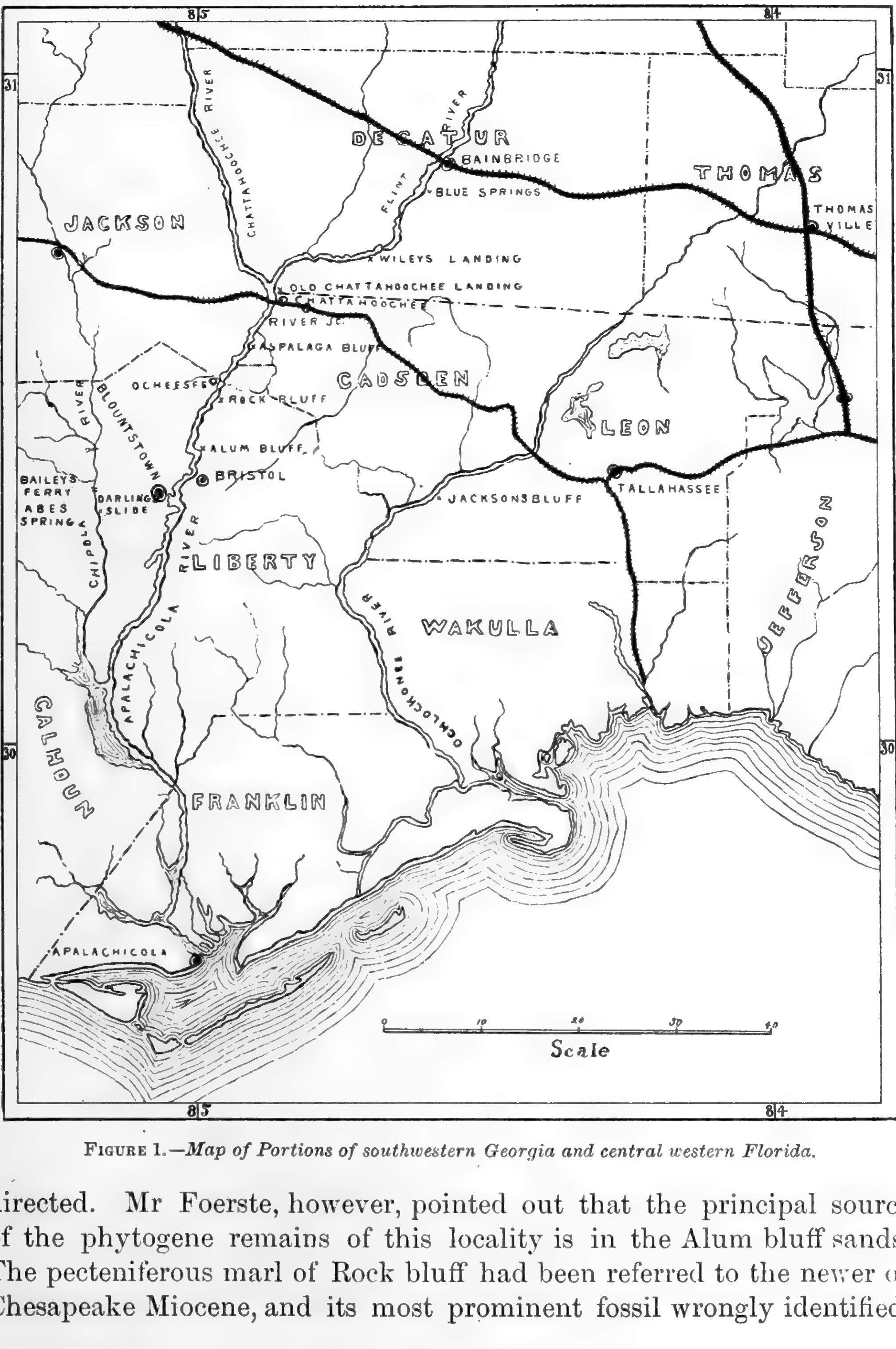


FIGURE 1.—*Map of Portions of southwestern Georgia and central western Florida.*

directed. Mr Foerste, however, pointed out that the principal source of the phytogene remains of this locality is in the Alum bluff sands. The pecteniferous marl of Rock bluff had been referred to the newer or Chesapeake Miocene, and its most prominent fossil wrongly identified.

Its correlation with the proper horizon in the Alum bluff section was necessary to a right understanding of the geology over a considerable area. Finally, the sections hitherto made had not been precisely located or exactly measured, part of the discrepancies alluded to doubtless arising from examination of the beds at different instead of identical points.

The season chosen for our work was that of the river's lowest stage, which, owing to drouth, was, as we were assured by old lumbermen, within two or three feet of the lowest water known to them.

It should be noted in passing that the identification of the various bluffs and landings is not easy unless one has an experienced riverman as guide, and in view of the fact that the maps are often incorrect, that changes in the location of landings and even of towns are made with great facility, and that places formerly occupied are now deserted, it is not surprising that travelers are misled as to local nomenclature.

### Area studied.

In making the investigations upon which this paper is based, the following plan* was adopted: We proceeded by rail via Atlanta, Macon and Thomasville to Bainbridge, the head of navigation on the Flint river, Decatur county, Georgia. There we procured two rowboats and floated down the Flint river to its junction with the Apalachicola at the Florida boundary, and thence down the latter river to Blountstown, Calhoun county, Florida, below which the low swamps of the coastal plain begin. This plan made it possible to camp at localities where investigations were to be made, and also to make such excursions inland from the river as were deemed desirable. The points visited are enumerated in the detailed statements presented later.

Descending the Flint river, the rocks, which belong to the Vicksburg series of the Eocene, characteristically distinguished by the presence of *Orbitoides mantelli* and *Pecten poulsoni* and *perplanus*, appear above the water at intervals only, and are separated by low areas where the red beds and alluvial mud alone rise above the river. The higher land exhibits the character of gentle, anticlinal folds through which the river cuts its way, forming bluffs which afford in most cases very good natural sections. The land at the river is usually somewhat lower than can be found a few miles away on either side, even at the bluffs, but owing to the thick mantle of gravel and rather dense undergrowth these more distant hills afford no convenient exposures. The number of parallel

* For most valuable suggestions and assistance we are especially indebted to Professor R. Pumpelly, Major T. B. Brooks, Professor E. A. Smith, State Geologist of Alabama; Mr Dubois and Mr R. A. Lytle of Bainbridge, Georgia; Mr Frank Burns and Mr Wood of Blountstown, Florida.

folds between Wileys landing and the edge of the coast swamps appeared to be not more than five or six, and as nearly as could be judged the folds are successively higher, culminating at Alum bluff, which reaches 161 feet above low water by careful measurement. Part of this difference in height may be due to the slope of the channel of the river seaward, but it is probable that a moderate increase in absolute height does take place. The bluffs along the river furnished convenient sites for Indian villages, and shards of pottery, arrow-heads, flint chips, excavations and other evidences of occupation are readily found.

## Localities in Detail.

*Bainbridge.*—Professor Pumpelly * has recently described the remnants of the Chattahoochee and Chipola beds which are found in various places about Bainbridge superposed upon the Vicksburg Eocene rocks, from which they are separated by an unconformity. These Miocene remnants represent what is left after solution by water and carbon dioxide has removed the greater portion, estimated by Professor Pumpelly as having reached in some places a thickness of 200 feet. Only the silicified fragments of rock and molds or siliceous pseudomorphs of the fossils now remain. Over and partly including them is an extensive series of reddish clays, sands and gravels, which of late have been referred to the Lafayette formation of Hilgard and McGee, covered by yellowish gray incoherent superficial sands (Columbian?) and a thin coating of humus. Elsewhere in this paper (page 169) reasons are given for the belief advanced by Professor Pumpelly that the red beds are of a composite nature, and to a greater or less extent, depending upon locality, are made up of residual material in its original location or but slightly transported by aqueous action. The remnants of small quartz dikes broken up into fragments but still retaining a nearly vertical position and of thin broken siliceous sheets hardly moved from their horizontality in the gravels seem to establish this fact beyond controversy. Elsewhere and espeally on the upper surface of the red beds, worn and rounded material testifies to a rearrangement and more or less transportation of part of the original material. As further seaward similar material covers beds later than the newer Miocene, it is probable that this part of the red beds of this region is of not earlier than Pliocene age.

*Blue Springs.*—At Blue springs, Flint river, Georgia, about four miles below Bainbridge, limestones with Vicksburg fossils are the prevalent rock, but above them Professor Pumpelly obtained fragments of highly silicified rock containing casts of *Orthaulax* and *Amauropsis burnsii*, be-

* Am. Jour. Sci., vol. 46, December, 1893, pp. 445-447.

longing to the Chattahoochee formation. This locality was not visited by us.

*Wileys Landing.*—At a place on the left bank of the Flint river a few miles above the Florida boundary line, known as Wileys landing, Professor Pumpelly states that the contact between the Vicksburg and undisturbed Chattahoochee Miocene may be observed. Unfortunately this interesting locality was missed, owing to a severe storm of wind and rain and the fact that our pilot was not acquainted with the place by that name.

*Old Chattahoochee Landing and Sections.*—The first stop of importance was made at old Chattahoochee landing, which is on the Apalachicola river just below the mouth of the Flint and in township 3 north, range 6 west, section 5. This was formerly a landing for river steamers, but is now superseded by the landing at the railroad bridge about a mile below. A single house stands on a mound near the river which formerly afforded a village site to the Creek Indians. From the old landing place two roads diverge, one toward the northeast, the other to the southeast. The latter is the older and no longer passable for vehicles, being gullied out by water. Both ascend the bluffs at a short distance from the river and come together on the hills a short distance beyond. A roughly levelled section was taken on each of these roads.

*Sections at Old Chattahoochee Landing.*

| | | |
|---|---|---|
| 1. Reddish sand and gravel, with streaks of clay | 20 to 40 | feet. |
| 2. Grayish yellow friable marl, with harder layers | 20 | " |
| 3. Greenish clayey marl, very adhesive | 2½ | " |
| 4. Chattahoochee limestone, with fossil casts | 4 | " |
| 5. Talus to water's edge, about | 3 | " |
| Total thickness | 49½ to 69½ | " |

This section was taken on the road running northeast from the landing.

| | | |
|---|---|---|
| 1. Reddish sands, gravel and clays | 15 to 20 | feet. |
| 2. Grayish yellow marl, friable | 20 | " |
| 3. Greenish clayey marl, sticky | 2½ | " |
| 4. Talus to water's edge, about | 3 | " |
| Total thickness | 30½ to 45½ | " |

Section number 2 was taken on the road which runs about southeast from the landing. The exposures are mostly in the gullies.

The fossil-bearing bed is number 4, and contains, among other fossils, echinoids, *Pecten* (Chipola sp.), *Arca* (like *transversa*), large solitary coral, *Venus penita*, *Lima* (like *scabra*), *Hemicardium*, *Ostrea*, *Loripes*,

*Scala*, *Plicatula*, *Divaricella*, *Pyrazisinus*, *Phorus*, all as poor casts; fish-bones, and ribs of some mammal resembling those of the manatee. No orbitolites were seen.

*Chattahoochee Landing.*—At New Chattahoochee landing, where the railroad-bridge crosses the river, the bank is chiefly alluvial mud, with fragments of rock from the Chattahoochee limestone. The railway-trestle continues eastward from the bridge, across land submerged at high water, about a mile to a point known as River Junction or Chattahoochee station of the Savannah, Florida and Western railroad. Here two roads divide; one, the above mentioned, extends into Georgia, the other eastward in northern Florida. Half a mile from the station, on the first mentioned road, there are several cuttings, where, under the usual red beds, 5 to 10 feet in thickness, the Chattahoochee limestone is exposed in place. Here it is a residual rock, clayey white and yellowish, with conchoidal exfoliation. The fossils have mostly been removed by solution and their traces are very indistinct, but nearer the station the same rocks are visible in the bottom of an excavation made to obtain material for an embankment. Here distinct imprints of fossils occur, and even poorly preserved shells in some places. In the first locality the Chattahoochee limestone rises some 5 feet above the track, covered with yellow and ferruginous clayey streaked sand, more clayey at the top, over which is about 3 feet of gray superficial sand and humus. At the second locality the rocks are 8 to 10 feet below the track, and here Burns in 1890 collected *Pyrazisinus cornutus*, *Cerithium hillsboroensis*, *Potamides transecta*, *Conus planiceps*, *Natica amphora*, *Lucina hillsboroensis*, *Cardita serricosta*, *Venus staminea*, *V. cancellata*, *V. penita*, *Cytherea nuciformis*, *Cyrena vesica* and *Orbitolites floridanus*. There were among the undetermined species *Tagelus*, *Solen*, an echinoid and some obscure corals.

*Aspalaga Bluff and Section.*—About five miles below the bridge, on the left bank, the first prominent bluff is that at Aspalaga landing. This bluff, which is in township 3 north, range 7 west, section 35, extends half a mile along the river, rising abruptly about 75 feet, and further back attaining a height of perhaps nearly as much more. The upper part of the bluff is sloping and much obscured by talus and vegetation; the lower part is nearly vertical, offering the thickest single exposure of the Chattahoochee limestone to be found anywhere on the river. The beach comprises a narrow strip of talus, but, from appearances, at least 10 feet of limestone exists below that part which is distinctly exposed. The limestone is composed of ill defined, nearly horizontal beds, alternating harder and more friable, partly free from organic remains and partly containing typical Chattahoochee fossils rather poorly preserved. A small piece of this limestone, with *Orbitolites* and other remains, was

found by Dr Foerste at a height estimated at 130 feet above the water, but this was doubtless transported in some way from below. At the highest point of the bluff, where this limestone showed the thickest exposure, about 40 feet were visible and ten feet more probably concealed by talus and water. Above it lies about 20 feet of bluish green marl, conformable to the limestone, and much of which is unfossiliferous. In places, however, there are layers of small oyster-shells and a *Pecten* which has somewhat the appearance of a young *Pecten madisonius*, and has been mistaken for that species. It is, however, a Chipola species, and may prove new. This marl was observed by Mr Jussen, whose manuscript section we confirmed on the spot; it is what Mr. Johnson has called* the "Aspalaga clays," assigning it a thickness of 60 feet; but his section is evidently too much generalized, and the bed did not exceed 20 feet in thickness at any point where we were able to observe it. Mr Johnson's heights were measured with a pocket aneroid and seem excessive; that method of measurement, without careful correction and comparison, being but little to be relied upon.

Above the marl at the edge of the bluff, omitting talus, there appeared to be about 5 feet of reddish clay and gravel, but further back this thickness is very greatly surpassed, and may reach 40 or 50 feet. On account of the manner in which the upper part of the hill is weathered and overgrown, a large amount of time and labor would have been required to expose and verify a complete section. We therefore confined our work to the verification of the actual section facing the river.

It is to be mentioned that in Mr Langdon's paper, previously alluded to, he gives a section at a point which he calls "Ocheesee," which subsequent observers have not identified, but which Mr Johnson suggests may be the same as Aspalaga bluff, which is not mentioned by Mr Langdon. The discrepancy in height and stratigraphy forbids us to accept this identification; and, indeed, we did not observe any place where the strata clearly recalled those mentioned in Langdon's section. At the present Ocheesee landing the bank is wholly of alluvial material, and is on the opposite side of the river, so Mr Langdon's section could not have been made there.

*Section at Aspalaga Bluff.*

| | | |
|---|---|---|
| Superficial sand, mostly absent at river | 0 | feet. |
| Reddish sands and gravel, with streaks of clay | 5 | " |
| Bluish-green clayey marl, with *Ostrea* and *Pecten* | 20 | " |
| Chattahoochee limestone, hard and soft layers | 40 | " |
| Talus to water (probably Chattahoochee) | 10 | " |
| Total thickness above water | 75 | " |

*Bull. Geol. Soc. Am., vol. 3, 1891, p. 129.

The section here was taken at the highest part of the bluff rising from the river and about midway between the two ends.

There is below low-water level probably 10 or 12 feet more of the Chattahoochee limestone, worn vertically or nearly so by the action of the current.

*Ocheesee.*—About three miles below Aspalaga, on the opposite side of the river (right bank), is Ocheesee landing, marked by several buildings, one of which was once a fine large frame house built on piers. The lower floor was apparently nearly twenty feet above the level of the water at the time of our visit, yet we were told that skiffs had been paddled in at the front door and out the back door, through the central hall, during one of the freshets. As the land is very level and not high within sight of the river, it would seem as if an incalculable amount of water would be required to raise the level to the height mentioned.

*Rock Bluff and Section.*—Below Ocheesee is a long stretch of river nearly straight, known as "Seven-mile reach." On the left bank, about two miles below Ocheesee, in township 2 north, range 7 west, section 19, rises Rock bluff, the face of the third principal anticline cut by the river below the Florida line. It creates a slight bend and offers an excellent, clean section. The settlement named Rock Bluff is four or five miles inland from the river-bank, and should not be confounded with the landing.

The lower part of the bluff formed by the Chattahoochee limestone is vertical, rising twelve feet above the water, and presumably nearly as much below it, at low stages of the river. Above this is a mass of marl varying from bluish green to gray in color, weathering white, more arenaceous below and more marly above, replete with oyster-shells, a fine, large *Anomia*, a pecten, like young *madisonius* (but, as observed by Foerste, only four-sevenths the size of that species; it is really a Chipola species); a *Turritella* and many *Balani*. This assemblage of species indicates a shallow water oyster-reef fauna, unquestionably belonging to the old Miocene and forming the shoal-water equivalent of the Chipola and Alum bluff beds, especially the latter. Above this marl lie the red Lafayette clays and gravels—in this case worked-over materials—variable in thickness, owing to denudation, but apparently averaging about fifteen feet, and covered with a thin layer of superficial soil and sand. This section was carefully measured with a steel tapeline, due allowance being made for the inclination of the tape from the vertical. It shows the finest and thickest section of the greenish marl exposed anywhere on the river. The contact of the marl with the Chattahoochee limestone is distinct and without apparent unconformity or transition beds of any kind.

The section was measured on the highest part of the bluff, which is the first approached as the turn of the river is made in descending.

*Section at Rock Bluff.*

| | |
|---|---|
| 1. Superficial sands, thin and variable, say | 3 feet. |
| 2. Reddish clayey sand and gravel, about | 15 " |
| 3. Greenish white compact marl, with fossils | 67 " |
| 4. Chattahoochee limestone, to water | 12 " |
| Total thickness above water | 97 " |

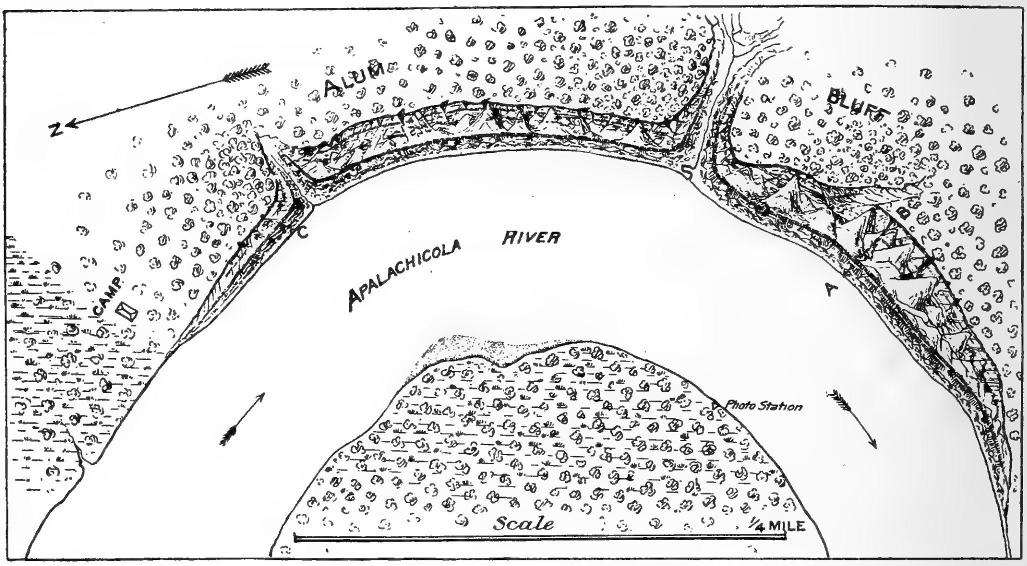


FIGURE 2.—*Sketch-map of Alum Bluff.*

*Alum Bluff and Section.*—Five miles below Rock bluff the reach terminates by a semicircular bend convex toward the west and followed by another convex to the east. The latter is bordered by a cliff called Alum bluff, which is in township 1 north, range 8 west, section 24. It is hollowed out of the fourth anticlinal fold south of the Florida line, extends for about half a mile on the left bank of the river, roughly northwest and southeast in trend, lower toward the north, highest in its southeastern third, and cut transversely somewhat southeast of its center by a small deep valley of erosion. The bluff in a general way may be divided vertically into two parts, the lower, forming a bench about midway, crowned by a layer of acid clay from which water issues, leaving a saline efflorescence on the face of the bluff, from which the latter derives its name. Standing at the foot of the bluff, nothing can be seen above this clay, the more arenaceous strata above having weathered back at a lower angle, though still nearly vertical above. Upstream above the bluff the river bank is a swamp, mostly of alluvial clay; the right bank

is little else as far as the eye can reach. Camp was made at the north end of the bluff. A section was most carefully made at the highest exposure, with steel tape, portable transit and stadia, a small baseline and triangulation being measured for that purpose; the weathered surface of the strata shaved clean with a spade and photographed; some of the fossil plants, being too frail to transport, were photographed *in situ;* a general panorama of the bluff was photographed from the opposite bank of the river, and some fossils with a series of rocks collected for analysis and study. The large collection obtained here in 1890 by Mr Frank Burns rendered it unnecessary to spend much time in searching for fossils.

The section was taken at the part of the bluff indicated by *A–B* on the sketch-map.

*Section at Alum Bluff.*

| | | |
|---|---|---|
| 1. Superficial sands | 8½ | feet. |
| 2. Red clay | 2½ | " |
| 3. Reddish and yellowish streaked sands | 66 | " |
| 4. Aluminous clay | 24 | " |
| 5. Chesapeake gray marl | 35 | " |
| 6. Alum bluff sands with streaks of clay | 21½ | " |
| 7. Hard Chipola marl to water (variable) | 3¼ | " |
| Total thickness above water | 160¾ | " |

The composition in detail of these several beds is as follows:

Number 1.—Pale yellowish gray incoherent sand.

Number 2.—Hard reddish clay weathering with vertical face.

Number 3.—Streaky yellowish and reddish sands with small little-worn gravel, of siliceous character, mixed with it. Near the lower third a few obscure impressions, possibly representing fossils, were observed by Mr Stanley-Brown. The lower 3 feet of the sands is more or less loamy from admixture with underlying clay. They are distinctly stratified in conformity with the other beds of the bluff.

Number 4.—Tough gray aluminous clay weathering nearly vertical with a very few fragments of vegetable matter in it, and some obscure indications of gastropod and bivalve fossils, the shells entirely dissolved and represented chiefly by color-marks in the clay. The appellation of "lignitic," heretofore applied to this clay on the authority of Mr Johnson, cannot be regarded as justified, as the amount of phytogene material is trifling. The fossils may have been marine or fresh water. No satisfactory evidence is afforded by their faint traces, as observed by us.

Number 5.—Bluish gray tough clayey marl replete with characteristic Chesapeake fossils, especially *Mactra congesta.* The upper six inches is discolored by iron oxide, derived from the water oozing from the bed above, which has also dissolved the shells, leaving only cavities. Toward

the north, at a point (*C* of figure 2) near the camp, the Chesapeake is thinned to 5 or 6 feet in thickness.

Numbers 6 and 7.—The Chipola marl is compact and of a dark-reddish color from hydrated peroxide of iron contained in it. The fossils which are abundant are rather soft. *Orthaulax* is the most common shell; there are no traces of *Orbitolites*. The matrix is chiefly sand mixed with clay. At least 6 or 8 feet of the Chipola is below the water; it rises at the lowest stage of the river from 3 to 11 feet above the water's edge, weathering almost like a rock. There is no well defined line of separation between the marl and the Alum Bluff sands (number 6) above it, but the change takes place in a space of 5 feet, the lower portion of the sands containing more or less of the Chipola fauna. Above this they are mottled bright ferruginous and yellow, and exhibit distinct marks of cross bedding. They contain sheets—laminæ or lenticular streaks of clay—which show abundant leaf remains resembling willows and other water-loving plants, while the sands in the lower part of the bed contain large leaves and stalks of palmetto or other palm-like vegetation, the thicker parts of which are reduced to the condition of lignite. These are too friable to remove without previous hardening applied *in situ*. The upper part of these sands did not show any fossil remains at the points where we examined them.

Toward the north (*C* of figure 2), where the bluff is much lower and the Chesapeake thinned out to 5 or 6 feet in thickness, the sands below it are unfossiliferous and modified. The upper part is more exclusively sandy, and, lower down, the bed assumes the clayey compact greenish color of the oyster marl at Rock bluff, a few miles above, but here the green marl contained no fossils.

*Jacksons Bluff and Section.*—In this connection, as confirming the identity of age and position of the greenish marl, a section taken by Mr E. Jussen, of the United States Geological Survey, may be cited. This section was made at Jacksons bluff, situated in township 1 south, range 4 west, section 17, on the Ochlockonee river, Florida, being about twenty-one miles east and six miles south of Alum bluff.

*Section at Jacksons Bluff.*

| | |
|---|---|
| Superficial sands | 5 feet. |
| Chesapeake bluish marl, with *Mactra congesta* | 8 " |
| Gray marly bed, with oysters and *Pecten* | 22 " |
| Total thickness | 35 " |

*Bristol*—From Alum bluff we descended the river to Bristol and Blountstown, the former a landing on the left bank in township 1 north, range 8 west, section 36, with the village of the same name about a mile inland from the river bank. At the landing alluvium and clayey beds

alone rise above the water. Between the landing and Blountstown, three miles westward, there is a shoal in the river, popularly reported to be rocky, but too much covered to be examined without a dredge.

*Blountstown.*—Blountstown, named from the village of an ancient chief called Blount by the whites, is in township 1 south, range 8 west, section 3, on the right bank of the river. A short distance above the landing is a large mound, formerly occupied by the Indians as a village site. The bank at this place, which contains several dwellings, a store, the county courthouse and a primitive jail, is chiefly composed of clayey alluvium, and is partly overflowed at high water in the river. High water in 1886 left a mark on the houses 4 feet above the ground. About eight miles westward is the Chipola river, flowing in a southerly direction, on the banks of which are several outcrops of the Chesapeake and Chipola beds, in which the fossils are in a better state of preservation than at Alum bluff, and the Chipola marl may be observed resting conformably upon the Chattahoochee limestone. The water being extremely low, within a foot or two of its lowest observed stage, as we were informed, the opportunity was extremely favorable for examining these outcrops. Obtaining a conveyance, we drove from Blountstown over to the Chipola river to inspect them.

*Baileys Ferry and Section.*—The principal localities of interest on the Chipola river are those near a point called Baileys ferry, where a bridge has replaced a former ferry, but no village exists, the farms being scattered. This ferry is not on any map, but is believed to be situated in township 1 north, range 9 west, section 32. Just above the bridge, on the right bank, the ferruginous Chipola marl may be seen rising two or three feet above the water's edge, the bank at the lowest stage of the water being six or eight feet high. This is said by residents of the vicinity to be the most northerly point on Chipola river where the yellow marl is visible in the bank. A few miles west, on a branch known as Ten-mile creek, the Chipola marl rises much higher and reaches so near the surface at Stevens spring that the plow throws out hundreds of fine fossils in turning a furrow. We were not able to visit Mr Stevens' place, but half a mile below the bridge, on the right bank, is a farm belonging to Mr John McClellan, on which a fairly good section can be studied along the river bank, and here the following section was made :

*Section at McClellans Marl-bed, Baileys Ferry.*

| | |
|---|---|
| Superficial sands, 1 to 3 feet, say .......... | 2 feet. |
| Chipola marl, varying from 7 to .......... | 12 " |
| Chattahoochee limestone at water's edge, extending below not less than.. | 6 " |
| Total thickness.......... | 20 " |

The marl is extremely rich in fossils; Mr Burns obtained over 400 species in a few days' work at this locality. It contains a certain proportion of clay and much calcareous matter, and is of a pale yellowish color. It shows no *Orbitolites*, but *Orthaulax*, *Cypræa*, *Ancilla*, *Fusus*, *Conus*, *Cerithium*, etc, show characteristic fossils beautifully preserved and of good size. It is probable that the beds which lie above the Chipola have been denuded in this vicinity. The importance of the section lies in the presence of the typical Chipola marl conformably upon the Chattahoochee limestones, which last at Alum bluff are below the surface of the river, if present. The left bank here seems to be alluvial.

*Abes Spring and Section.*—Three or four miles south from Baileys ferry, on the left bank, is a settlement of scattered houses which from a spring which issues near the river has received the name of Abes spring. It is situated on the south line of township 1 south, range 9 west, section 17. The right bank of the stream here seems to be low and alluvial, rather densely wooded.

The section here was measured with a steel tapeline on the left bank of the Chipola river, Calhoun county, Florida, at the bluff about 200 feet north of the spring, which here flows from a wooden pipe.

*Section at Abes Spring.*

| | | |
|---|---|---|
| 1. Superficial sands, about | 4 | feet. |
| 2. Reddish and yellowish streaked sands | 30–32 | " |
| 3. Gray aluminous clay | 19 | " |
| 4. Chesapeake gray marl to water (variable) | 7 | " |
| Total thickness above water | 62 | " |

In detail these strata have the following composition:

Number 1.—Pale yellowish gray incoherent sand, such as might be deposited by a river during seasons of high water—less like beach-sand than the analogous material at Alum bluff.

Number 2.—Of the same character as number 3 of Alum bluff. The material is generally a little coarser and the gravels a little larger, and there is also greater heterogeneity in structure.

Number 3.—Same as number 4 (aluminous clay) of Alum bluff.

Number 4.—Chesapeake, just as at Alum bluff.

*Darlings Slide and Section.*—On the Chipola river, a mile or more north of Abes spring, is a "slide" where timber is cast into the river for the construction of rafts, which are floated down the river to the mills at Apalachicola, on the Gulf. This place is locally known as Darlings slide, and is a very steep natural bank, affording an excellent section, though

somewhat obscured by weathering and the friction of the enormous logs which are rolled over it. It is on the left bank, and the bank opposite is low and apparently of alluvium.

*Section at Darlings Slide.*

| | |
|---|---|
| 1. Superficial sands | 3 feet. |
| 2. Reddish and yellowish streaked sands | 18–20 " |
| 3. Gray aluminous clay (presence or thickness uncertain) | } 27 " |
| 4. Chesapeake marl to water (variable) | |
| Total thickness above water | 50 " |

The composition of the several beds is as follows:

Number 1.—Pale yellowish gray incoherent sand, such as might be deposited by a river during floods—less like beach-sand than the analogous material at Alum bluff.

Number 2.—Of the same character as number 3 of Alum bluff. The material is generally coarser and the gravels a little larger. There is also greater heterogeneity in structure.

Number 3.—The conditions were unfavorable for determining the presence or thickness of the gray aluminous clay, but from the fact that it is well exposed with sharp contacts at Abes spring, but a short distance south, and, together with the Chesapeake, makes up 27 feet of thickness, it is reasonable to suppose that it forms part of the 27 feet assigned to 3 and 4.

Number 4.—Chesapeake marl, in every respect the same as that formation found at Alum bluff.

It is notable that nothing below the Chesapeake is visible, although it has been stated that the Chipola beds exist under the gray marl. This can only be an assumption, since, with the water, as we were informed, within a foot of its lowest stage, nothing of the sort was visible, nor does the stream show any material such as would be washed out of the older Miocene beds, if present. The principal fossil here, as at Alum bluff, is *Mactra congesta*, Conrad, with which are associated *Venus mercenaria*, L., and *Turritella variabilis*, Conrad. The beds above the Chesapeake appear to be destitute of fossils.

Below Abes spring the banks of the Chipola become lower and swampy and the river enters the so-called Dead or Chipola lakes, noted as a fishing ground, through which it connects with the Apalachicola by a cut-off. Seaward from this extend the great swamps of the coastal plain.

*Thomasville, Georgia.*—On the line of the Savannah, Florida and Western railroad leading toward Albany, Georgia, and from half a mile to a mile from the center of the town, there are several cuts which give good exposures of the reddish gravels which cover most of this region and have been referred to the Lafayette formation. These beds contain much

clay, together with small, slightly rounded fragments of quartzose material, and near their upper surface numerous small, dark colored, very round gravel stones, quite uniform in size, stained with iron and looking like peas or buckshot. The lower part of the clays shows evidences of stratification, thin sheets of harder material still remaining, broken up, apparently *in situ*, but formerly continuous. Occasionally a small dike of quartzose material may be seen standing in the gravel in its original position.

## Conclusions as to the Geologic Structure and Succession.

The different portions of the generalized section for the Apalachicola region above the Vicksburg limestone which have actually been observed are shown on the accompanying diagrams, together with a column representing the whole series. The relative thickness of the beds is accurately represented in the diagrams, except that in the ideal column the thicker beds are somewhat diminished in order to bring it within the limits of the page. It will be seen on examination that, while the series is not complete in any single section, taken collectively there is no gap outstanding between the beds and, humanly speaking, no room for misapprehension as to their position and age. Being variable in thickness at different points, an average thickness has been assumed for the ideal section, except in the case of the Chattahoochee limestone, which has been put at 50 feet, and the Vicksburg at a nominal thickness, owing to exigencies of space.

To avoid possible confusion the symbols used in the sections are also employed in the sterographic map accompanying the paper. This map, while approximately accurate in its geographic boundaries, is necessarily highly generalized topographically and is merely a conventional presentation of the relation of the several localities and formations.

### *EOCENE.*

Beginning at the base of the column, Professor Pumpelly has shown that the Chattahoochee series rests on an erosion surface of the Vicksburg or Orbitoidal limestone which forms the culmination of the Eocene rocks. We have confirmed this by an examination of the fossils submitted by Professor Pumpelly, who also considers that the Chattahoochee and Chipola beds in southwestern Georgia attained a thickness of some 200 feet, which has been reduced by solution and settlement to a very small fraction of that amount.

### *MIOCENE.*

*Chattahoochee Limestones.*—At Aspalaga the Chattahoochee limestones are in evidence to the amount of 50 feet before disappearing below the

water and talus to an unknown depth. They consist of clayey limestones, some layers of which are harder than others, occasionally thor-

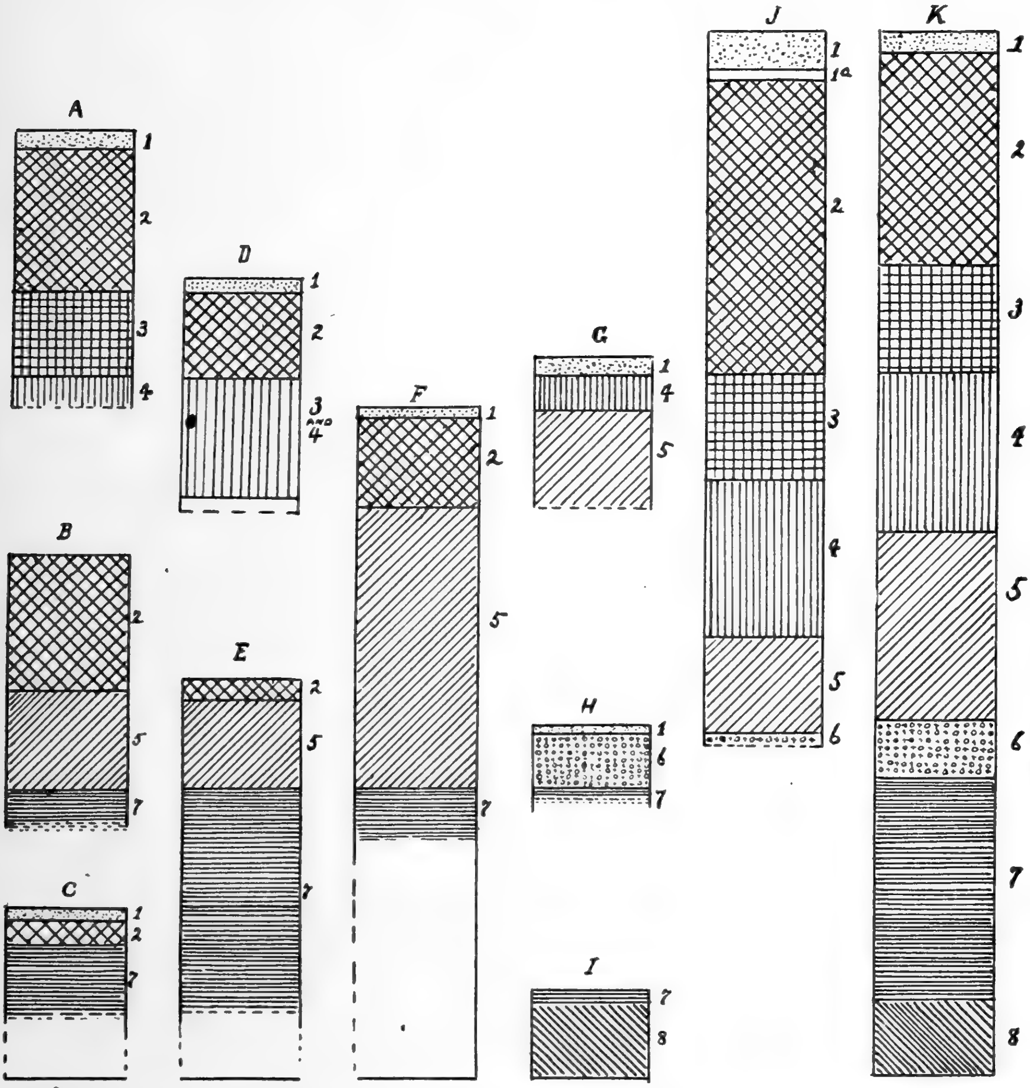


FIGURE 3.—*Generalized Section and Sections exposed on the Chipola, Apalachicola and Ochlockonee Rivers, Florida.*

A. Section at Abes spring, Chipola river, Florida.
B. " " Old Chattahoochee landing.
C. " " River junction, Savannah, Florida and Western railroad.
D. " " Darlings slide, Chipola river.
E. " " Aspalaga bluff, Apalachicola river.
F. " " Rock bluff, Apalachicola river.
G. " " Jacksons bluff, Ochlockonee river.
H. " " McClellans marl-bed, Baileys ferry, Chipola river.
I. " " Blue springs, Flint river, Georgia.
J. " " Alum bluff, Apalachicola river, Florida.
K. " " Ideal section showing relative thickness and succession of the beds.

The definitions assigned the figures are as follows: 1, superficial sands; 2, Lafayette beds; 3, aluminous clay (Pascagoula?); 4, Chesapeake marl; 5, Alum bluff beds; 6, Chipola marl; 7, Chattahoochee series; 8, Vicksburg Eocene limestones.

The figures are the same for all the sections. In sections A to J the relative thickness of the beds is represented on the natural scale.

oughly silicified, usually of a pale yellow color, but in the more siliceous portions white or gray or, when partially oxidized, varying in shades of ferruginous brown. The remnants left by solutionary processes are almost always reddened by oxidation. The beds which in other parts of Georgia and Florida may be correlated with the Chattahoochee series are as follows: The Hawthorne beds of central Florida and the thin layer containing oysters and corals which Burns found intercalated between the Vicksburg limestone and the Altamaha grits on the Ocmulgee river in Georgia, the Orthaulax bed and Tampa limestone of Tampa, Florida, and the chert of Hillsborough river. Heilprin's Cerithium rock also belongs here, and Bailey's "infusorial earth" of Tampa. The fauna which characterizes them is also found represented mechanically mixed with later forms in the marls of Shiloh, New Jersey.

This fauna is very closely allied to that of the Chipola beds and has not been completely worked out, but is intimately connected with the Miocene of the West Indies, Jamaica, Trinidad, Haiti, Curaçao, Panama and Costa Rica. Many of the species are the same as those of the Chipola fauna, but others are peculiar, sufficiently so to warrant the separation of the Chattahoochee from the Chipola as a distinct series. The forms which characterize the former alone, as far as our present knowledge goes, include *Orthaulax pugnax*, several species of *Pyrazisinus*, *Cerithium hillsboroensis*, *Potamides transecta*, *Natica amphora*, *Cyrena vesica and Orbitolites floridanus*. The last has been repeatedly mentioned as found in rocks of the Chipola series, and there is no particular reason why it should not occur there, since there is a recent species of *Orbitolites* not to be distinguished from *Orbitolites floridanus*, which has been dredged in large quantities on the Gulf coast by the United States Fish Commission. Nevertheless, the fact remains that so far I have been unable to detect any trace of this fossil in any of the typical Chipola beds, and believe that the report of its presence there is due to some misidentification. Certain corals and a peculiar oyster are very characteristic of the lower zones of the Chattahoochee everywhere, but have not yet been sufficiently studied to be precisely identified, and may also occur at higher levels. The same may be said of several echini. Since the Altamaha grits are of analogous and probably synchronous origin with the much-debated Grand Gulf beds, it is probable, from Burns' observations, that the latter are in large part synchronous* with the Chattahoochee series; and the erosion by which the Grand Gulf sediments were formed may have started with the movement in elevation which finally raised these older Miocene beds in Costa Rica to a very considerable height above the sea.

* See Bull. 84, U. S. Geol. Survey, pp. 82, 83, 1892. Professor E. A. Smith, State Geologist of Alabama, from unpublished data had come to the conclusion as early as September, 1892, that the typical Grand Bluff beds should be correlated with the older Miocene of the Apalachicola section.

The Chattahoochee limestone has been observed above the Vicksburg in southwestern Georgia (Bainbridge, Blue springs, Wileys landing), and in Florida, at the surface or overlaid only by the Lafayette (River Junction), conformably overlaid by the Chipola marl (McClellan's marl-bed, Chipola river), or by the Alum bluff beds (Old Chattahoochee landing, Aspalaga, Rock bluff).

*Chipola Marl.*—The Chipola marl which immediately overlies the Chattahoochee limestone is a very calcareous mixture of broken shells, fine clay, fossils, and fine sand. When in its normal state it is of a pale yellow, but at Alum bluff is oxidized to a dark red. It is replete with organic remains which are often in a fine state of preservation. More than 400 species have been collected by Burns and the writers, of which only a portion of the Gasteropods have been fully worked out. *Orthaulax gabbi*, *Strombus aldrichi*, *Venus langdoni*, many *Cerites* and *Turritellas*, *Marginellas* and Trochids are among the more conspicuous fossils. There is a remarkable absence of foraminifera and echinoids and the corals are few, mostly small, solitary species. The deposit is one which must have been formed under very favorable conditions of food-supply and in a depth of water greater than that which occurs within the limits of the tides. This explains its absence in the sections where the Chattahoochee is covered by beds which were obviously deposited in shallow water, as at Aspalaga, Rock bluff and old Chattahoochee landing. The observed thickness of the Chipola bed does not much exceed 15 feet, but in favorable localities it may hereafter be shown to have considerably exceeded this amount.

*Alum Bluff Beds.*—At Alum bluff the Chipola marl is conformably overlaid by the deposit named by Dall in 1891 the Alum bluff beds, which there attains a thickness of nearly 22 feet. The change at the point *A–B*, figure 2, from the marl into the sands is not abrupt, but gradual, and takes place in a depth of about five feet, the fauna of the marl-bed being represented in the sands by quite a number of its species in this transition zone. Above the sands show no fossils or only phytogene remains. The composition of the Alum bluff beds is chiefly sand, with a little clay intermixed, and occasional apparently lenticular masses of clay almost pure. The sands are yellowish or pale; the clay pale gray, both oxidized in streaks, when they are of various shades of ferruginous yellow verging into orange. When the face of the bluff is cleared of weathered material the sands above the lower five or six feet are seen to be clearly and distinctly cross bedded. In the lower portion are numerous plant-remains, some of them, apparently palmettos, attaining a very large size and having the woody stems converted into streaks of lignite. The phenomena indicate clearly, as Foerste has

already shown, that an elevation took place which raised the area of the marl to a point where the deep-water fauna forsook it, where vegetable matter was deposited, and where finally the water was so shoal as to admit of cross bedding from wave-action. These features are characteristic of the beds at the point *A–B*, figure 2, where our chief section was made; but, following them northward in the face of the bluff for about a third of a mile, we perceive that a change takes place in the character of the sediments of which the bed is composed. They become more clayey and the sand is finer; the color changes from pale yellow to whitish, and finally to a pale gray or even a greenish tint. At point *C*, figure 2, the transformation is complete, and the yellow color and cross-bedding have disappeared entirely. In the bed at this point we did not observe any fossils, but its thickness is about the same as at *B*. Five miles further north, in the Rock bluff anticline, this bed reappears with a thickness of 63 feet, and here contains oyster-bed fossils, *Ostrea*, *Pecten*, *Balanus*, *Anomia* and *Turritella*, and it is again seen with the same fossils at Aspalaga. At Old Chattahoochee landing it is again unfossiliferous. It is also reported under the Chesapeake, at Jacksons bluff, on the Ochlockonee river, where it has the same fossils as at Rock bluff. This deposit clearly belongs to the Chipola series and represents that part of the latter which was deposited in shallow water, before the incursion of the Chesapeake fauna, during an epoch of elevation. The greatest thickness of the Alum bluff beds observed at Rock bluff is 63 feet. They were subsequently named the "Aspalaga marl" by Johnson,* and referred to his "Waldo formation," but they are physically continuous with the sands of the Alum bluff beds.

Farther west, at Oak Grove, on the Yellow river, Florida, what appears to be this same fauna occurs in a fine incoherent gray sand, with a number of species not found in the Chipola marl, including the *Turritella* (n. sp.), referred to as occurring at Rock bluff. It would seem, therefore, that this same zone is represented at that point, though the matrix is different. With a large number of these essentially old Miocene fossils collected at Oak Grove were sent by Professor E. A. Smith specimens of *Pecten madisonius*, *Panopæa goldfussii* and several other fossils, which latter occur in the Chesapeake at Alum bluff, but not in Maryland. These may represent a stratum above that in which the old Miocene fossils occur, or these species may be the precursors in that part of the Alum bluff beds of the advancing Chesapeake fauna. At present, owing to various circumstances, which need not be recapitulated here, we incline

* Bull. Geol. Soc. Am., vol. 3, p. 130. On page 129 they are called in a foot-note the "Aspalaga clays," but clay is not predominant in them. The Waldo horizon is that of the newer Miocene (Chesapeake) at the typical locality, but its author in defining it combined with it beds at other localities belonging to the old Miocene.

to the first supposition. There is a well marked *Cardium* (*chipolanum* n. sp.) in the Chipola marl which simulates in miniature the great *Cardium magnum* of the recent fauna. This is succeeded in the Alum bluff beds by another species extremely similar, but perfectly distinct. This occurs at Oak Grove. *Cardium chipolanum* is found in Johnson's Hattiesburg phase of the Grand Gulf beds at Roberts, Escambia county, Alabama. At the latter place Professor Smith informs us the sands containing the fossils lie directly upon genuine Grand Gulf beds (Johnson's Ellisville phase). If these observations be correct we probably have the Grand Gulf beds (strictly speaking) comprised between the Hawthorne beds below and the Alum bluff beds above, thus making them chronologically equivalent to the lower middle portion of the old Miocene rocks of west Florida. The Pascagoula clays of Johnson, formerly associated with the Grand Gulf beds, may be confidently referred to the newer portion of the newer or Chesapeake Miocene, and would therefore be separated by a considerable time-interval from the typical Grand Gulf rocks.

There is some reason to believe from fossils collected at De Funiak springs that the Alum bluff beds are represented there, but no question of this sort can be answered permanently without a careful study of the stratigraphy in combination with an intelligent knowledge of the fauna. Attempts to theorize on the geology of the southern Tertiary from a few imperfectly identified species of fossils and without exact determinations of the stratigraphy are worse than useless, as they multiply error and confusion.

The Chipola series may be summarized as containing the Chipola marl, the Roberts, Escambia county, Alabama, sands and the Alum bluff beds, which, with the Chattahoochee formation, comprise the subtropical or old Miocene division of the Miocene of the southern and eastern United States.

*Chesapeake or cold Water Miocene.*—Just above the Alum bluff beds in the section *A–B*, at Alum bluff, lies the gray Chesapeake or newer Miocene marl, consisting of an arenaceous greenish gray clay, crammed with fossils. Here the bed is deposited conformably upon the Alum bluff sands, but sharply contrasted with them, both in color and coherence. It reaches here a thickness of 35 feet, which diminishes gradually northward to not more than 5 or 6 feet at point *C*, figure 2. The upper few feet form a zone which is more or less oxidized and has the fossils dissolved out, owing to seepage of acidified water from the bed above. The fauna of the Chesapeake at Alum bluff includes about 200 species, among which *Venus rileyi*, *Conus adversarius*, *Turritella variabilis*, *Fusus equalis*, *Dentalium attenuatum*, *Ecphora quadricostata* and *Crucibulum constrictum*

are prominent species and *Mactra congesta* the most abundant fossil. The color of the bed and of the fossils in the bed is exactly like that of the Maryland beds of the same age, their cold gray and chalky white color contrasting vividly with the yellow and ferruginous tints of the old Miocene marl and its fossils.

This bed has been recognized lying upon the Alum bluff beds at Jacksons bluff, Ochlockonee river (Jussen), and below the Lafayette or red beds and the aluminous clay at Abes spring and Darlings slide. It also occurs near Tallahassee and is reported on Johnson's authority from De Funiak springs. It is probable that this fauna, which has been shown by Dall and Harris* to have penetrated into the gulf of Mexico by the strait named by them the Suwannee strait,† never extended westward of the Mississippi embayment, the synchronous fauna on the Texan side of that gulf partaking much more strongly of subtropical and Pacific coast elements. It would not be surprising if, as suggested by Foerste, a mingling of the earlier Chesapeake and latest Chipola species were found to occur at some point on the Gulf coast. But it must be distinctly understood that no reliable evidence of such a mingling, as distinguished from an accidental mechanical mixture of fossils of different ages, has yet been shown to exist anywhere. The Oak Grove fossils authorize the inquiry, but cannot as yet offer any proof of such a mixture. The locality would be worth examination by any trained observer who would take the time and trouble to definitely ascertain the exact facts, which are not yet at our disposal.

The Chesapeake marl reaches 7 feet above the water at Abes springs. At Darlings slide there is uncertainty as to its exact thickness, but at neither place is its base discernible or any subjacent rock visible. At Jacksons bluff it is 8 feet thick.

*The Aluminous Clay.*—Above the Chesapeake marl at Alum bluff is a bed of grayish clay, apparently more pervious than the marl, as water issues from it all along its face, and, trickling down, leaves an efflorescence on the surface, from which the bluff derives its name. This clay is 24 feet thick, and was termed "lignitic" by Langdon and Johnson, but contains extremely little vegetable matter, as Foerste pointed out.‡ We found evidences of fossils, too much dissolved to identify, in this clay, and Mr Foerste states that he found Chesapeake species in it, but does not mention which species. It is highly probable that the clay is of Chesapeake age, and, as it exactly resembles the so-called Pascagoula clay of Vernal, Mississippi, which contains at least one Chesapeake spe-

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* Bull. 84, U. S. Geol. Survey, 1891.

† Op. cit., p. 111; the name of Okeefinokee has since been applied to it by Foerste (Am. Jour. Sci., vol. 46, October, 1893, p. 245), who doubtless overlooked the fact that it had previously been named.

‡ Op. cit., p. 250.

cies (*Mactra lateralis*, Say) belonging to the newer Chesapeake, it is probable that the Pascagoula beds should also be referred to this horizon. The aluminous clay was also recognized in a bed, 19 feet thick, above the Chesapeake marl at Abes spring, and part of the 27 feet assigned to the Chesapeake at Darlings slide is probably of this horizon, though, owing to the verticality of the bluff, its face could not be closely examined at this height, and the line of distinction between the two, if it exists, had been so obscured by the rush of huge logs over the surface that it could not be recognized from the foot of the bluff.

This completes the summary of the Miocene section of the Apalachicola region. It has involved some repetition of previously mentioned details, but this was thought best to avoid obscurity.

### *PLIOCENE.*

There was found near the top of every section studied on the Apalachicola river a bed which in general was composed of a mixture of yellow and red colored sands and clays, the predominating tint and composition of the material varying with the locality. The thickness of this bed in each case has been shown in the descriptions of the sections. It has already been noted that in the vicinity of Bainbridge this material is of considerable thickness and homogeneous in texture, highly argillaceous and of a uniform red color throughout; also that in some places it has the appearance of a decomposition product *in situ*, while in others rearrangement of the material is apparent, yet each so simulating the other as to make identification at times difficult. This condition of affairs continues with considerable uniformity northward to Macon, but it is safe to say that there is greater heterogeneity in this material in the limited area studied than there is in its greater northward extension. At Old Chattahoochee landing it preserves its Bainbridge characteristics and rests upon an erosion surface. At Aspalaga and Rock bluff modification is more noticeable, and when Alum bluff is reached on the seaward route this formation is represanted by a bed nearly 70 feet thick, highly arenaceous, fine in texture; in color, orange and white, so alternating as to present a mottled appearance, and, while even this portion of the bluff has a stratified aspect, there is some evidence of plunge and flow structure. It also rests conformably upon the bed of aluminous clay which immediately overlies the Chesapeake. A little farther south and 12 or 15 miles to the westward, at Abes spring and Darlings slide, the sand of which it is composed is coarser, the mottlings have a marked red and yellow color, plunge and flow structure is more pronounced and, as at Alum bluff, it rests apparently conformably upon the aluminous clay overlying the Chesapeake. From our observation we conclude that, though often different in composition, structure and color, it is never-

theless a continuation of the more homogeneous formation to the northward, the modifications having been brought about by the agencies to which it was subjected in its seaward extension. There would seem to be no question as to the propriety of referring it, as we have done, to the Lafayette of Hilgard and McGee, and from the studies of the fossil-bearing beds alone it can be stated with a reasonable degree of certainty that it is not earlier than the Pliocene.

### *PLEISTOCENE.*

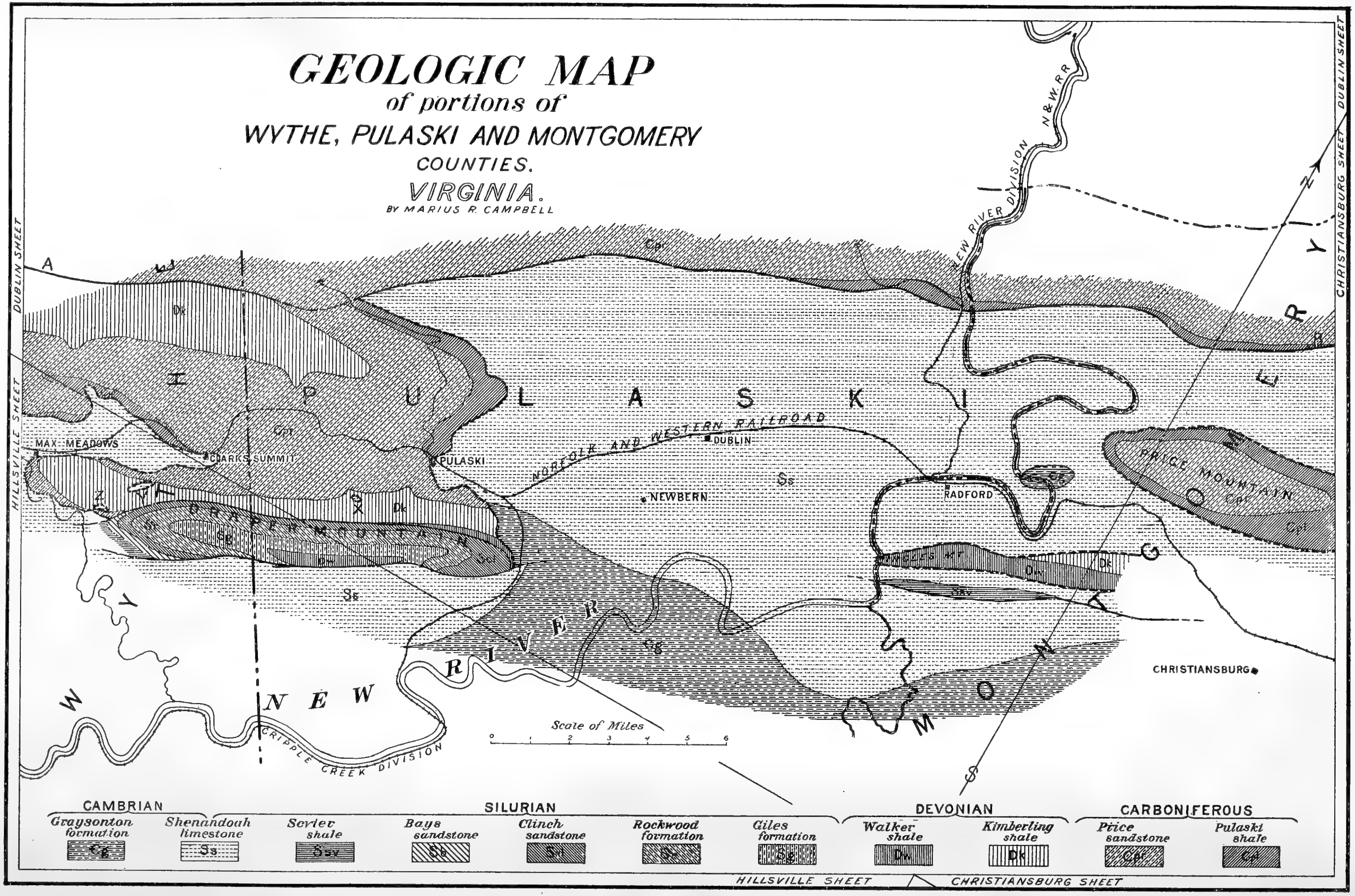
In almost every instance there was observed resting upon the preceding formation a veneer 3 or 4 feet thick of incoherent, superficial sand, which in nearly all cases has the appearance of such fine sandy material as is deposited in the sea by the sluggish southern rivers. At Alum bluff it presents more the aspect of washed beach-sand, but in all exposures examined bowlders and large pebbles were conspicuously absent. The opportunities for studying this surface bed were too limited to warrant the presentation of any positive opinions as to its relation to similar materials of the region to the eastward or westward. It is probably, however, a remnant of the Pleistocene Columbia, which, along the seaward portion of North Carolina, South Carolina and Georgia, has been found by McGee and others to cover the Lafayette as a mantle of varying thickness.

### CORRELATION.

The following preliminary correlation of the Miocene beds differs slightly from that of Bulletin 84, United States Geological Survey, and also from that of Mr Foerste, owing to the receipt of additional material and our personal later observations on the ground. More knowledge is required both of the fossils and the stratigraphy before a finality can be reached in the correlations, but as far as the Apalachicola section itself is concerned, we believe it now rests upon a solid foundation.

| *Apalachicola Section.* | | *Correlatives.* |
|---|---|---|
| Aluminous clay | | Pascagoula clays (?) |
| Chesapeake marl | | Chesapeake of Virginia and Maryland. |
| Alum bluff beds | Grand Gulf beds. | Hattiesburg phase of Grand Gulf beds.<br>Oak Grove sand. |
| Chipola marl | | Roberts, Alabama, sand.<br>Bainbridge residual beds, Georgia. |
| Upper Chattahoochee beds | | Bainbridge, Georgia, residual beds.<br>Altamaha grits.<br>Ellisville phase, Grand Gulf (?) |
| Lower Chattahoochee beds | | Typical Grand Gulf.<br>Hawthorne beds of Georgia and Florida. |
| Vicksburg Eocene | | Vicksburg Eocene. |

The total thickness of this Miocene will hardly exceed 200 feet along the Apalachicola river.


GEOLOGIC MAP
of portions of
WYTHE, PULASKI AND MONTGOMERY
COUNTIES.
VIRGINIA.
BY MARIUS R. CAMPBELL
PULASKI
MONTGOMERY
WYTHE
NEW RIVER
MAX MEADOWS
CLARKS SUMMIT
PULASKI
DUBLIN
NEWBERN
RADFORD
CHRISTIANSBURG
NORFOLK AND WESTERN RAILROAD
NEW RIVER DIVISION N.&W.R.R.
CRIPPLE CREEK DIVISION
DRAPER MOUNTAIN
PRICE MOUNTAIN
DUBLIN SHEET
HILLSVILLE SHEET
CHRISTIANSBURG SHEET
Scale of Miles
0 1 2 3 4 5 6
CAMBRIAN
Graysonton formation
Shenandoah limestone
SILURIAN
Sevier shale
Bays sandstone
Clinch sandstone
Rockwood formation
Giles formation
DEVONIAN
Walker shale
Kimberling shale
CARBONIFEROUS
Price sandstone
Pulaski shale

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# PALEOZOIC OVERLAPS IN MONTGOMERY AND PULASKI COUNTIES, VIRGINIA*

BY MARIUS R. CAMPBELL

(*Read before the Society December 28, 1893*)

CONTENTS



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## Area Studied.

### *GENERAL DESCRIPTION.*

Along the line of the Norfolk and Western railroad in the counties of Montgomery, Pulaski and Wythe, Virginia, there is an area of complicated geology which up to the present time has not received the attention it deserves. The region in question extends from Christiansburg, on the east, to Max Meadows, on the west, and embraces a strip of country from ten to fifteen miles in width and about equally divided north and south with respect to the line of the railroad.

### *PREVIOUS INVESTIGATORS AND THEIR CONCLUSIONS.*

From time to time numerous geologists have examined the rocks in this region, but their work has been only cursory and their results are vague and unsatisfactory. The published reports concerning it are, so far as the writer is aware, those of W. B. Rogers,* J. P. Lesley,† W. M. Fontaine,‡ J. J. Stevenson § and McCreath and d'Invilliers, || who have uniformly regarded the phenomena here displayed as due entirely to faulting.

That similar phenomena can be produced by faulting is not to be questioned, for in the southern Appalachians there are cases too well authenticated to admit of a doubt; but in this immediate region the evidence is far from conclusive, and in fact strongly suggests an entirely different mode of formation. The object of this paper is to present the conclusions reached and, as far as possible, the facts upon which they are based.

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* Geology of the Virginias.

† Am. Phil. Soc. Proc., vol. ix, pp. 30–33.

‡ Am. Jour. Sci., third series, vol. xiii, pp. 37–48 and 115–123.

§ Am. Phil. Soc. Proc., vol. xxiv, pp. 61–108.

|| The New River-Cripple Creek Mineral Region of Virginia.

### *PRESENT INVESTIGATIONS.*

During the past season the writer has done considerable field work in this territory, and though the area examined was mainly confined to that embraced within the limits of the Dublin atlas sheet, still enough of the adjoining territory was covered to render the main structural features apparent. The work is not intended to be final; hence the map accompanying this paper simply embodies the results obtained, and is provisional and subject to revision in its details. Its main features, however, are essentially correct, but differ so widely from those determined heretofore that the writer deems it well to present them now, believing that they have an important bearing on many perplexing questions regarding the structure and stratigraphy of this portion of the Appalachian valley and indirectly of the whole eastern portion of the continent.

### *PHYSICAL FEATURES.*

Physiographically this area is the southward extension of the Shenandoah valley or, more truly, the northward extremity of the Great valley of East Tennessee. It is bounded on the northwest by the first of the prominent valley ridges, Little Walker or Brushy mountain, from which it is separated by the first great structural break, Walker Mountain fault. On the southeast there is no topographic boundary to the field, the map simply representing the area studied, but it includes the major portion of the valley. Macks mountain, the southeastern limit of the valley, is but three or four miles distant from New river, but it involves the undetermined Ocoee sediment and is purposely omitted from the map.

The general surface of the region under consideration is a peneplain that probably dates back to Tertiary times for its origin and represents a period when the general elevation of this portion of the continent stood much lower than at present. Since then the history has been a repetition of oscillations, but the aggregate amount of these movements has resulted in the uplifting of the peneplain to its present altitude, about 2,200 feet above sealevel. The streams, acting under the stimulus of this rapid increase of gradient, have cut deeply into the plain in their effort to keep pace with the rapid increase in elevation. The New-Kanawha river, being the largest stream in the region, has cut most deeply into the level surface, but even this stream has not held its own against the general uplift; consequently today we find it flowing at an elevation ranging in this area from 1,700 to 2,000 feet, and its channel marked by rapids and small falls, showing that it is still very active in its work of reaching a baselevel.

The small streams are also in a season of great activity, but have not been able to keep pace with the river in its rapid cutting; still the surface is deeply trenched and the old baselevel is not recognizable unless one has a comprehensive view of the valley and can bring the remnants of the baselevel into his plane of vision. From Christiansburg to Pulaski and around the southern side of Draper mountain to Max Meadows this peneplain is the controlling element in the topography, but between Pulaski and Max Meadows, on the north side of Draper mountain, along the railroad, there is no trace of a baselevel, for the rocks are sandstones or sandy shales and were not reduced to a peneplain during Tertiary times.

The most conspicuous topographic feature in the region is Draper mountain, a faulted syncline of heavy sandstone. The shape is characteristic synclinal topography, the fault cutting off one side of the perfect canoe-shaped basin, but leaving a narrow ridge on the northern side connecting two hooks that mark the points of the basin. These extremities are in the form of sharp knobs and are conspicuous features in the topography. Peak knob is at the eastern extremity and stands at an elevation of 3,374 feet, while Hamilton knob, at the western extremity, is but 3,163 feet above sealevel. The ridge connecting them is extremely narrow and steep, being formed of a single plate of heavy sandstone with a steep southerly dip, while the softer beds lying above it have been eroded, leaving a marked synclinal valley on the south side of the mountain.

North of Draper mountain is an exceedingly rugged country, composed of sandstones and shales. On either side of the railroad is a range of knobs formed by the harder beds of sandstones; these knobs are not remarkable for altitude, but constitute a formidable barrier on account of their rugged character and brushy covering. Those north of the railroad are called the Peak creek hills and trend parallel with the railroad until just west of Pulaski, where they swing sharply around the point of an anticline and then trend due west toward the Altoona coal mine.

East of New river there are also a few hills dignified by the name of mountains, though but a few hundred feet above the surrounding plain. The most noted of these is Price mountain, north of the line of railroad and between Christiansburg and Radford. This is an isolated knob three or four miles long and 300 to 400 feet high. From a physiographic standpoint it is quite insignificant, but from its economic resources is well and widely known, as it has furnished coal for local use throughout the valley for many years, notwithstanding lack of transportation facilities and the small scale upon which its mines have been worked.

South of Radford are two small ridges—Ingles and Berringer mount-

ains, which, in a structural sense, are of equal importance with any described, but they are physiographically insignificant and without mineral resources of value.

*STRATIGRAPHY.*

The Paleozoic rocks are quite well represented in this district, with the exception of the extreme top of the series. The formations showing in outcrop are, beginning with the oldest, as follows:

*Cambrian—Graysonton Formation.*—A complex mass of red and green shales and interbedded limestones; the limestones are generally siliceous, showing a gradual transition from the siliceous green shale to a solid limestone, the whole highly charged with iron and giving rise to deep-red soils; occasionally a bed of pure blue limestone is seen, but they are not common. No reliable estimate of its thickness could be made, as the succession of beds was not determined and no regular section could be found that would afford a reliable measure. It is generally much crumpled and disturbed, and has the appearance of being closely folded; the folds do not appear to sustain any definite relation to the main structural features of the region, and the writer is inclined to believe that they owe their present disturbed condition more to folding that occurred in early Paleozoic time than to that which culminated the Appalachian revolution and produced the structural features now most prominent. The age of this formation cannot be definitely stated, as it is apparently unfossiliferous, but seems to be perfectly conformable to the Shenandoah limestone and immediately beneath it, so that it is probably of Middle or Lower Cambrian age.

*Cambro-Silurian—Shenandoah Limestone.*—This is equivalent to the Valley limestone of Rogers, and includes the lower portion of the Silurian and the upper portion of the Cambrian periods. It is very much folded and crushed, and this folding is of the same type as that described in the preceding formation. Its thickness is about 4,000 feet, and it is generally a gray dolomite, slightly cherty at some horizons, and at its extreme top there is a few feet of a blue, sparingly fossiliferous limestone, which is probably the only representative of the Trenton-Chazy limestones in this region. The lower portion is somewhat shaly, so that the soil is apt to show some fragments of a white or yellow shale. In the vicinity of Radford this formation carries heavy beds of limestone conglomerate; these beds or rather masses appear to be free from bedding planes, and in only one place could their attitude relative to the regularly bedded limestone be determined. On the bank of the river, two miles below Radford, where the railroad has made a sidehill cut, the face of the cliff is well exposed and shows the contact of the conglomerate and lime-

stone. The limestones are somewhat folded, and were evidently eroded previous to the deposition of the conglomerate, for the surface upon which the conglomerate was laid down is smooth and regular and cut across the edges of the folded strata below. The conglomerate is composed of yellowish white chalk-like matrix, in which are embedded pebbles of a character similar to the matrix. The pebbles are of various sizes, from grains as large as the head of a pin to masses from six to nine inches in diameter, and more or less rounded. In a few cases the smaller grains are of foreign material, but the whole is so deeply decayed that it is difficult to determine the genesis of the rock. In places it seems like a subaërial deposit, while in others it appears like a true water-deposited conglomerate. Its meaning is obscure, but the writer is of the opinion that it indicates the existence of overlaps in early Paleozoic time, probably during the deposition of the Shenandoah limestone itself; that the limestone was folded and elevated above sealevel and formed cliffs, along which the masses and half rounded fragments washed from the bank were recemented and formed these curious deposits of conglomerate.

*Silurian:* Sevier (Hudson River) Shale.—But two exposures of this shale are known to exist in the region. One of them lies south of Ingles mountain, on the east side of New river, and is structurally a shallow, faulted syncline of not more than three or four miles in length and half a mile in breadth. In this area the formation consists essentially of calcareous shale, but with many thin beds or lenses of highly fossiliferous limestone. In character these shales agree perfectly with the exposures to be seen along New river northwest of the region in question, and were obviously deposited under similar conditions; but further west, along the valley, the character is quite different, and certainly points to a different origin and a different mode of accumulation. In the vicinity of Wytheville there is a shallow basin, composed of sediments of the same age as those already described, but very different in composition. These consist almost entirely of soft felspathic sandstone or sandy shale, originally somewhat calcareous, but generally the calcareous matter has disappeared through weathering and nothing but the sand remains. This phase does not reach Walker mountain on the northwest, and terminates somewhere between Wytheville and Radford. The line marking this change in character passes near the western extremity of this region and probably constituted somewhat of a barrier between the two areas of deposition. On the western slopes of Hamilton knob this formation is supposed to outcrop, but nothing definite is known of either its character or the extent of its exposure.

Bays (Red Medina) Sandstone.—This is also supposed to be present on Hamilton knob, but, like the Sevier shale, was not studied sufficiently to enable the writer to describe either the formation or its outcrop.

Clinch (Medina-Oneida) Sandstone.—A coarse white or slightly mottled sandstone, varying in thickness in this portion of the valley from 100 to 250 feet. It is the most conspicuous member, as it is the chief ridge-making formation, and much of the surface is covered with its débris. In this immediate region it differs slightly from its general aspect, for here it carries imbedded between its massive layers at least one bed of soft red shale about six or eight feet in thickness. Its total thickness is probably the minimum as given above, but that is somewhat uncertain, as it is faulted where measured and so affords no positive evidence.

Rockwood (Clinton) Formation.—This formation consists almost entirely of shales, some of which are non-fissile and highly fossiliferous, containing crinoid stems in abundance. Its thickness was undetermined, and the formation is of no consequence, except that by its fossils the age of the sandstone forming Draper mountain was positively determined.

Giles (Lower Helderberg-Oriskany) Formation.—Lying above the Rockwood shales, on the south side of Draper mountain, is a formation exceedingly difficult to classify, as its exposures are rare and unsatisfactory. The only rock exposed is a blue, crystalline limestone, the probable equivalent of the Helderberg, and it is not known whether there are any sediments properly belonging to the Oriskany or not; there is apparently room for them, but nothing shows.

*Devonian:* Walker black Shale.—This constitutes the lower portion of the great series of Devonian shales and is separated entirely by its color. It is a black, carbonaceous shale, and the passage from this into the green shale above is very gradual and is accomplished by interbedding, so that it is impossible to determine exactly where the line should be drawn. It is arbitrary at best, and serves only to show that the base is essentially a black shale which, in a broad way, is clearly distinguishable from the green shale above.

Kimberling Shale.—This division includes all of the shales above the Walker and beneath the Carboniferous sandstone. Its base is the transition series, already described; these pass upward into green, argillaceous shales, which grow more sandy as we ascend, until in the upper portion it carries many thinly bedded sandstones and some conglomerates.

*Carboniferous:* Price (Pocono) Sandstone.—Above the Devonian sediments, but separated by no distinct line, is the important coal-bearing formation of this region; it consists of an alternating series of coarse yellow or green sandstones, beds of shale and coal. In character these sediments resemble closely those of the Upper Coal Measures in the Appalachian basin to the northwest, but it is a significant fact that the deposits of coal thin out rapidly to the northwest, across the strike, as

| Campbell | Darton | Butts |
|---|---|---|
| | | Chemung |
| Kimberling Shale | Jennings Sh. | Brallier = Upper Portage = Gardeau (Hatch) |
| Walker Shale | Romney Sh. | Millboro = {Lower Portage = Naples; Marcellus} |

well as southwestward along the valley. Toward the northeast the writer is unacquainted with them, but they apparently hold their own for a long distance in that direction. The distribution of the coal affords a clue to the conformation of the shoreline of the Carboniferous sea, and seems to indicate that here, where the coals are thickest, the coastline could not have been far distant to the southeast.

Pulaski Shale.—This immediately overlies the preceding formation and is quite conspicuous in the landscape from its brilliant color. Some geologists have inclined to the belief that this series represents the limestone and red shales of the Umbral, but an examination of the rocks in the Cove in Wythe county entirely disproves this idea, for the limestones rest directly upon these red shales which are as fully developed there as at Pulaski or on New river; also this band of red shale can be traced across the valley into West Virginia, where it has diminished in thickness to about 20 feet, but is still persistent. In the same region the Umbral red shales are very prominent in their correct position above the limestone. There is one exposure that seems to sustain the theory of these shales belonging above the limestone; this is west of Hamilton knob, where the road south from Max Meadows leaves the hilly country of the Devonian and Carboniferous sandstones and shales. Here the Carboniferous limestone immediately overlies the sandstone, with no red shale between; but the writer inclines to the belief that there is a slight overlap of the Carboniferous limestones upon the Price sandstone, and that the red shales were either not deposited here or were eroded previous to the deposition of the limestone.

## *STRUCTURE.*

*General Features.*—The structure of this region is much more complicated than the stratigraphy, and has been the cause of the uncertainty respecting the general geology of the region. As has been mentioned before, this area, together with the belt lying along the eastern side of the Appalachian valley throughout its whole extent, has been subject to disturbing influences throughout Paleozoic time. The earlier folds are masked and in part obliterated by the later movements, and the prominent structural features of today are those produced by the latest of these periods of activity. The foregoing statement does not agree with the old and popularly accepted idea of the Appalachian revolution, which is that all the folding of Appalachian type occurred in post-Carboniferous time, and that previous to this the entire valley region was under water-level. This old idea is rapidly giving way before the mass of evidence that is accumulating, and which proves conclusively that considerable of the folding occurred in Lower Silurian times, and probably

was continuous, with some interruptions, up to the close of the Carboniferous era.

The age of the last disturbance in the region under consideration cannot be fixed definitely in geologic time. That it occurred after the deposition of the Carboniferous limestone is certain, for in the regions immediately adjacent this formation is involved in the folding of Brushy mountain. The evidence for fixing the limit in the other direction is not so good, and we cannot positively say whether it occurred before the great Carboniferous conglomerate was laid down in the coal basin to the northwest or whether it was folded after all the Carboniferous sediments were deposited. The available evidence is negative, but indicates that the region of the Great valley southeast of the coal field along the New river was above sealevel when the coal was forming in the basin to the northwest, and if this is correct the folding in the valley region probably antedated it.

The most prominent structural feature due to this latest period of disturbance is the Walker mountain fault, shown on the map at *A–B*. Northwest of this fault the structure is quite regular and all the formations appear to be present in their regular order of sequence. South of the fault the condition of the formations is quite different and, as they bear no very close structural relation, will be described in detail.

*Price Mountain:* General Description.—Northwest of Christiansburg and north of the line of the railroad lies Price mountain, a low ridge not more than 300 feet above the general level of the surrounding country, and between three and four miles long. The region surrounding this small mountain mass is composed of the Shenandoah limestone, and in structure bears no relation to the structure of the mountain. The latter is an anticline, the core of which is composed of the sandstones, shales and coals of the Price formation. Around the margin of this formation is a belt, varying in width, of Pulaski red shale, which dips in all cases away from the center of the mountain at angles varying from 15° to 35°. From the center of the mountain, erosion has removed the red shale and cut deeply into the underlying Price sandstone. The outer margin of this peculiar area was followed quite closely, excepting the eastern extremity, east of the Christiansburg-Blacksburg road, in order to determine the nature of the unconformity. Along this road nothing but the Pulaski shale shows in a broad, flat-lying belt that terminates within a mile to the eastward in a broad, rounded point. The line of contact is generally marked by a belt of level land, in which no rocks are visible. On the southern side, however, in the vicinity of Vickers switch, the contact is along rather high land, but the same indefiniteness characterizes the junction line. In but one place were the Pulaski shales and the Shen-

andoah limestone found in close proximity, and that is in the bed of Stroubles creek at the western extremity of the area. Here the purple sandstone and shale strike northeast and southwest, and dip 35° to the northwest, while the limestone within fifty feet has the same strike, but stands vertical.

Views of other Geologists as to Origin.—Faulting has heretofore been assumed as the cause of this isolated anticline of Lower Carboniferous rocks. J. P. Lesley, in his account of this region,* describes these faults in the following indefinite way:

> "In Price mountain, between Blacksburg and Christiansburg, the two coal-beds, with their slates and red shale formation above them, have been curiously let down, still in an anticlinal form, between two faults, so as to be inclosed between two valleys of Lower Silurian limestone."

He also gives a cross-section through Price mountain, drawn in accordance with the above description, but he fails to explain the peculiar ending of the formations, both east and west, and the singular fact that the red shale is in contact with the limestones around the entire margin, an occurrence that could hardly be produced by the kind of faulting described.

W. M. Fontaine has given a more detailed description of this mountain, but seems equally at a loss to account for its peculiar structure. He describes it as follows: †

> "The structure of this field, which bears the name of Price mountain, is one of the most curious products of the force which has produced the numerous faults in this region. . . . The field seems to be a prism of Vespertine strata, engulfed by a double fault in the limestone, with its eastern end tipped lower than the middle and western portions. The dip, of course, is nearly north and south, away from the crest, and toward the limestone.
>
> "The amount of contortion and rubbing exhibited by the strata is surprisingly small. The roof and floor of the openings made are as uniform and smooth as those of our upper coals of the West. As a consequence, the coal is worked with ease, and unlike that of Brush mountain, two miles off, shows but little rubbing, and may be taken out in blocks of any size."

J. J. Stevenson‡ gives a similar description of the structure of Price mountain, but does not add anything new in the shape of a suggestion as to the origin of the present structure.

The foregoing quotations show that the present knowledge regarding the structure of the mountain is very indefinite, and that the solutions proposed are without that full knowledge of the details which can only be obtained by careful mapping.

* Am. Philos. Soc. Proc., vol. IX, p. 37.

† Am. Jour. Sci., third series, vol. xiii, pp. 117–118.

‡ Am. Philos. Soc. Proc., vol. xxiv, p. 69.

The structure of Price mountain was quite carefully studied by the writer, and but two explanations seemed at all applicable to account for the present anomalous structure.

Its Formation by Faulting discussed.—The phenomena described can be accounted for by faulting in only one way, and that is by a broad, flat overthrust, such as are common in the extreme southern Appalachian and have been described before this society by C. W. Hayes.* In such a case it is reasonable to conclude that, in common with all such known overthrusts, the mass overthrust must have come from the southeast; but from where in the southeast could such a mass have come? This is the last known exposure of these rocks in that direction, and it is difficult to conceive from whence this mass could have been thrust Again, while it is just possible that in an overthrust of this kind one horizon only of the overthrust mass should come in contact with the strata underneath, it is decidedly improbable and certainly militates against such an origin. Lastly, the contact phenomena, as far as they were observed, do not resemble fault phenomena, for in this type of faulting there are generally places where the different rocks can be seen in close proximity if not in actual contact, and in all such cases the formations in contact, if they be soft and yielding beds, show great contortion. This should be especially marked in this case, for the overlying beds are very soft, and a thrust of this extent must necessarily have crumpled them very much; yet the red shales are perfectly regular and show no greater dip nor greater irregularity near the line of unconformity than in the interior of the area. At the only point where the beds near the line of contact were seen the red shales had the regular outward dip due to the anticlinal fold, but the limestones beneath were much contorted, due probably to earlier folding.

The condition of the coal-beds in Price mountain as described by Fontaine is still further evidence against faulting of any kind, for if such violent overthrusts as are required to produce this structure had actually occurred, the softer members of the series would have certainly shown some effects of the force. An isolated mass like Price mountain, thrust into its present position, would have suffered much worse than Brushy mountain, which is simply a portion of a faulted syncline. Altogether the evidence does not seem to sustain the theory of faulting unless the conditions attending the faulting were almost abnormal and decidedly improbable.

Its Formation by unconformable Deposition discussed.—The peculiar relation of the sandstones and shales of Price mountain to the adjacent limestone suggests the possibility of an overlap of these Lower Carbonif-

* Overthrust Faults of the Southern Appalachian, Bull. Geal. Soc. of Am., vol. 2, pp. 141-154.

erous sediments upon the limestone. This hypothesis agrees better with the known facts than any theory of faulting yet proposed. The condition necessary for such a deposition is a depression in the limestone along the axis of what is now Price mountain and the occupation of this depression by probably an arm of the sea. When this depression occurred and whether there are other formations below the Price sandstone of course can only be conjectured, but it seems probable that the sedimentation in this basin was limited to Carboniferous times. In this depression, formed by local folding of the strata, the original mantle of soil would probably be preserved and the newly deposited material would be laid down upon it. This sedimentation culminated with the deposition of the Pulaski shale; consequently today around the margin we find an unbroken layer of this shale in contact with—not the limestone but the limestone soil that had been formed previous to the subsidence. The elevation that closed the period of sedimentation in this basin must have occurred immediately after the Pulaski shale was deposited, for it seems hardly possible that any later formation was deposited on this area and subsequently eroded, for in such a case either there would be found remnants of that formation or the red shales would have been cut away by the great erosion necessary to remove its cover. So the period of elevation and probable folding would appear to have been contemporaneous with the formation of the Carboniferous limestone over the adjoining areas, and from the same fact its effect would seem to have been local and of short duration.

There is an apparent difficulty in the way of accepting this hypothesis, and that is in the character of the sediments found in the different basins. The strata in Price mountain cannot be distinguished from those of Brushy mountain or the area west of Pulaski. This would seem to indicate a continuous deposit over the entire area rather than deposition in local basins. Again, the entire absence of so-called shore phenomena, such as conglomerates and other coarse sediment is particularly noticeable. While it is impossible for us to restore the exact conditions under which these sediments were deposited, we are safe in assuming that the immediate land-area was composed of the Shenandoah limestone, and in all probability would soon be reduced to baselevel, and then would be a neutral element in the question of sedimentation; the sands and clays washed down by the streams would furnish the material, and under such conditions the sea margin would be free from cliffs, and so the strata then forming would be free from conglomerates and all coarse sediments, except sandstone, deposited by the ocean currents; but the whole question of sedimentation is at present in a state of such obscurity that it is almost impossible to say what should and what should not have been

the character of the sediments deposited in these basins, and this is especially true when we know so little of their source and the attitude of the land surface from whence they were derived. In the opinion of the writer the evidence favoring an overlap vastly overbalances the negative evidence derived from the sedimentation.

*Ingles and Berringer Mountains.*—These mountains have a structure and history similar to Price mountain. Like it, they are surrounded by the Shenandoah limestone, or rather rest upon it unconformably, for their measures are entirely of Devonian age, and the interval must represent a great time-break.

Ingles mountain is a small double ridge south of Radford and on the south side and parallel to the old "Rock road." It is composed of a sandstone which appears to be interbedded with the Walker black shales and presents the same evidence of overlap as does Price mountain. It has been lifted into an anticline in the same manner, and now the crown of the arch is cut through, leaving two nearly parallel ridges of sandstone, dipping moderately away from the axis in either direction. At their western extremity, on the bank of New river, these two unite around the end of the anticline and make a conspicuous showing in the cliffs of the river. The sediments in this supposed basin correspond much better with our ideas of shore deposits, for the sandstone forming Ingles mountain is heavier near New river and apparently thins eastward to but a few feet in a distance of five miles, and presumably in the direction of the open sea. East of Ingles mountain the "Rock road" crosses this belt of Walker black shale, leaving the main mass on the northern side of the road.

Berringer mountain is formed by the Kimberling shales, which come in on the northern side of the area. Its eastern termination was not worked out; so that at present it is impossible to state definitely whether the line of contact along the northern face of Berringer mountain is a fault or a line of overlap, but it appears to be a fault.

*Cambrian Area at Peppers Ferry.*—Between Price and Berringer mountains the limestone is greatly disturbed, and several areas of Cambrian (Graysonton) shale occur. One of these areas was found along New river just above Peppers ferry, five miles below Radford. This was not examined thoroughly, but the contact on the south between the purple shales and the Shenandoah is thought to be a normal boundary, while on the northern side of the area there are some heavy quartzites in direct contact with the limestone. Whether this is an overlap or a fault could not be determined. An interesting fact in connection with this Cambrian area is the great amount of limestone conglomerate to be found in its immediate vicinity; especially on its northern side the con-

glomerate is very heavy, forming a cliff just below Peppers ferry forty or fifty feet high. The key to this structure will probably be found along the railroad in the direction of Christiansburg, where the structure is evidently quite complex.

*Syncline of Sevier Shale south of Radford.*—South of Ingles mountain there is a shallow syncline of Sevier shale lying perfectly conformable to the limestones beneath. The presence of this remnant of shale does not make it positive that the formation was originally deposited over this entire region and then eroded before the later overlaps occurred. True this would be the natural and reasonable supposition if it were not for the presence of a conglomerate near the top of the Shenandoah limestone. This occurs in many places between this area and the edge of the great Carboniferous formations on the northwestern side of the valley. Near Pearisburg, in Giles county, this conglomerate is finely exposed in the bed of Stony creek, showing the regularly bedded limestone alternating with beds of heavy conglomerate. This conglomerate has a calcareous matrix and pebbles of sandstone, quartzite, vein quartz and chert, some of which are four inches in diameter and generally flat and well worn. This certainly points to shore conditions near this locality; but the conglomeratic phase is widespread, and would seem to indicate numerous shorelines, possibly an archipelago with structural islands of limestone, from which the cherty material was obtained. If such conditions as this prevailed on the northern side of the great Appalachian valley, it certainly is not unreasonable to suppose that similar processes were going on here, and that this small area of Sevier shale may be but a deposit in a narrow structural basin and no contemporaneous deposit occurred over the limestone areas adjacent.

*Pulaski-Max Meadows Area:* Overlap north of Pulaski.—From Radford to Pulaski no trace of this peculiar structure could be found. The country is entirely limestone, still badly contorted. In the vicinity of Pulaski there are well shown the same structural features which have already been described in Price mountain. Northwest of Pulaski there is an anticline whose axis trends approximately east and west, and which, as it extends westward, brings up successively lower and lower formations. North of Wytheville the lowest formation exposed is the Sevier shale, while at the Wythe-Pulaski line the Kimberling shale is the lowest member. This formation forms a point about three miles northwest of Pulaski, and the Price sandstone encircles this point with a range of knobs called the Peak hills. These hills are cut off near the Altoona coal mine by the Walker Mountain fault, but they are in contact with the same sandstones of Little Walker or Brushy mountain. Around the margin of this formation the Pulaski red shales are

found in a crescentic line of outcrop, and like Price mountain they are everywhere in contact with the Shenandoah limestone, or rather the soil derived from that limestone, for in no place was the actual contact observed. Everywhere along this line from Pulaski to the Walker mountain fault the contact is marked by a belt of level land in which no exposures are to be found and the surface is composed entirely of a light gray limestone soil somewhat covered by overwash from the red shale. At Pulaski the formation comes to an abrupt end, whether from non-deposition or from erosion it is impossible to determine. North of Pulaski the structure is very simple, being a broad anticlinal point, with light dips in every direction away from the axis.

Overlap south of Pulaski.—From Pulaski to Draper mountain the strata are quite sharply upturned and strike directly against the limestone along the line of contact; this has the appearance of a line of overlap along which there has been considerable movement since the deposition of the Carboniferous sediments. How far the strata south of Pulaski have been thrust upon the limestone by this fault it is impossible to determine. This disturbance has folded and broken the beds, so that erosion has been quite active, and doubtless much of the overlying strata has been removed, so that originally the Pulaski shale may have extended several miles further east than it shows today.

The line of unconformity from Draper mountain to Brushy mountain has been regarded as a line of faulting by all who have described it, but apparently upon the grounds of an unconformity rather than from any observed evidence of faulting either in the actual line of contact or its relation to other structural features of the region. South of Pulaski there is evidence of some faulting along the line of contact, but north of the town the writer could see no evidence of such a thrust as would be necessary to produce the phenomena presented. These phenomena are identical with those observed on Price mountain and point to a common cause, which the writer believes is the unconformable deposition of the Carboniferous strata upon the contorted Shenandoah limestone.

Syncline west of Pulaski.—West of Pulaski the strata dip regularly southward from the Peak creek hills with an average dip of 30° into a broad, flat syncline whose axis is approximately along the line of the railroad.

Faulted Anticline south of Max Meadows.—South of this axis the strata again rise to the faulted anticline on the northern slope of Draper mountain, where the lowest stratum exposed is the Walker black shale, occurring at the eastern end of the mountain and lying in direct contact with the Clinch sandstone. This anticline terminates westward in the

hilly region just south of Max Meadows, where the core of the arch is composed of the Kimberling shale. West of Hamilton knob the Price sandstone comes in on the southern side of this anticline, forming a curious cross-ridge of quartzite running from near Hamilton knob to Max Meadows. This anticline is completely bordered by Shenandoah limestone from west of Hamilton knob around through Max Meadows and eastward to Clarks summit, which is the easternmost extension of the limestone. This boundary has many features common to the lines of unconformity already described, so that it is regarded as a line of overlap, but near Max Meadows it also shows considerable disturbance, which indicates movement along the plane of juncture.

Relation of Shenandoah Limestone to Devonian Shales on Hamilton Knob.—In the vicinity of Hamilton knob there are some isolated outcrops of limestone that probably afford more positive evidence of the unconformable deposition of the Devonian and Carboniferous sediments upon an irregular surface of the Shenandoah limestone than any other yet found.

A few years since, when the great wave of mineral development swept over the South, a company was organized to develop the deposit of iron ore that accompanies this interesting exposure of limestone. A furnace and rolling mill were built at Max Meadows, a narrow-gauge road constructed across the Devonian hills to this locality, extensive washers erected and mining begun on quite an extensive scale. Unluckily the deposit was found to be of quite a limited extent and the ore lean, so that the boom soon collapsed without accomplishing anything in a commercial way, except sinking a large amount of money. The excavations made in their search for ore have proved of great value to the geologist, for they afford him exposures of rock and contact phenomena that otherwise would have been impossible to obtain.

This area of limestone, marked *Z* on the map, is located on the brushy spurs of Hamilton knob probably 200 feet above the stream draining the area. A north and south section through this exposure shows a normal condition of the country rocks that is an exact counterpart of the section further west where the creek cuts the outer ridge. North of the limestone is the slightly disturbed sandy shales belonging to the upper Devonian, while on its southern side and directly in contact is a characteristic dark fissile shale, slightly fossiliferous, agreeing with a similar shale that shows in the gap of the ridge west of the limestone and lies just below the heavy Price sandstone. In the ore banks at the limestone outcrop these shales are considerably crushed and disturbed, and a little higher on the slopes of Hamilton knob the heavy Price sand-

stone, much contorted and apparently broken up, shows also. It is not continuous to the westward with the sandstone showing in the creek section, because the main fault has here cut it out for a short distance. The correspondence between the two sections is so close that there can be no question about the sequence. Everything is normal except the limestone, and all the evidence goes to show that this is a projecting boss that rises from below and now appears to penetrate the shales. This limestone was examined by McCreath and d'Invilliers* in connection with the ore, and was pronounced by them to be of Carboniferous age, but they neglect to state the evidence upon which they based their statement.

The outcrop was examined by the writer quite carefully in order to obtain some definite evidence as to its age, but no fossils were found. It is a gray siliceous limestone, in places quite crystalline, and is certainly cherty, for there were found in the clay resulting from the disintegration of the limestone, along the line of contact, badly decomposed cherts. In almost all respects it resembles the Shenandoah limestone, but does not bear any resemblance to the Carboniferous limestone. The ore is found in pockets and small particles scattered through the clay. Altogether the evidence is regarded as conclusive, and determines this limestone to be the Shenandoah. The appearance in the ore-pit confirms this view, as the limestone appears to descend indefinitely, with a wall of shale on either side rising at least 50 feet above the lowest exposure of limestone; so that the writer came to the conclusion that it was a projecting boss of limestone, around which the Devonian shales had been deposited, and the presence of iron ore, occurring, as it almost invariably does, on the southern side of the limestone, probably marks an old soil of residual clay from which the iron has segregated. It is true that in the movements which have since taken place a great amount of crushing has occurred along the line of contact, but this in no way affects the evidence. Again, about a mile due north of this area another of these limestones, marked *Y* on the map, was found, only here it is free from ore and is a much larger exposure. It has all the characteristics of the Shenandoah limestone, but rises out of the Devonian shales in a narrow exposure, probably three-quarters of a mile long and not more than 200 feet in width. Both of these exposures have their longer axis on a line almost due north and south and coincident, so that it has the appearance of a narrow fold in the Shenandoah limestone, parts of which were eroded, leaving isolated exposures on a line from Hamilton knob to Clarks summit. At the latter place the limestone is again exposed, and again

*The New River-Cripple Creek Mineral Region of Virginia, p. 141.

has ore been mined on its southern margin, but this area is connected now to the westward with the great limestone belt at Max Meadows. Before leaving the subject of these isolated bosses of lower limestone the writer wishes to call attention to another such area, marked *X* on the map. This the writer did not see personally, but from the description of his assistant judges it to be of the same character as those already described—a limestone boss projecting through the highest members of the Devonian shale.

The limestone area reaching from Max Meadows to Clarks summit appears to have been considerably disturbed and possibly faulted, but not to any great extent, but along its northern margin the rocks are very regular west of Clarks summit. The red shales are there in contact with the limestone throughout a very sinuous line of outcrop, and owing to a slight wrinkle in the sandstone they project far into the area of sandstone north of Max Meadows. South of this point of red shale there is an anticline of sandstone, around the eastern end of which the red shale is wanting, either through non-deposition or through subsequent erosion. Again it comes in on the southern side of the anticline in contact with the limestone, but does not continue far to the westward before it disappears altogether. This disappearance is possibly due to faulting, as a fault of considerable magnitude occurs on this line further west.

*Draper Mountain.*—The structure of this mountain is very simple, being a regular syncline of Upper Silurian rocks, the southern limit of which is faulted off. The details of structure about the western end or Hamilton knob were not worked out, but are apparently simple. Throughout most of the extent of the mountain this entire syncline is faulted on its northern side, and thrust forward or northwestward until now it rests upon the anticline of Devonian rocks, the Clinch sandstone being in immediate contact with the Devonian shale. Around the eastern end the geology was worked out more carefully. Here the fault cuts just below the Clinch sandstone, and this heavy stratum lies upon the Devonian black shale, which occurs above the highest ore pits in this vicinity. Below the black shale, at the extreme eastern end, there is no rock visible; the surface is a débris-covered slope on which considerable iron ore has been found, together with much residual chert. The presence of chert on this slope makes it extremely probable that the limestone from which it is derived belongs to the Shenandoah, but the outcrop is so deeply covered that it is impossible to determine its limits. Here, as in many places described, this line of unconformity is marked by a line of iron-ore deposits, and, curiously enough, they always appear on the southeastern margin of the limestone area.

## Summary.

In conclusion, the results of this work may be briefly stated to consist of the determination of the existence of a land-surface in this portion of the valley, from the beginning of the Devonian up to the time of the deposition of the Carboniferous limestone. This necessarily involves two periods of disturbance; one folded the limestones and produced the basins in which deposition took place, the other elevated these basins and brought to a close the period of sedimentation, and also probably folded the strata into the form it shows today.

The establishment of these two periods of disturbance is the important fact which, taken in connection with other well established periods of overlaps shows a somewhat regular distribution of these disturbances throughout Paleozoic time.

The earliest period known, indicated by *A* in figure 1, is that which occurred in lower Cambrian time, and is represented by the overlap of Chilhowee mountain.* This folding, so far as known, is limited to a narrow zone on the southeastern side of the valley, and is probably represented in this vicinity by unconformities in Lick mountain, a few miles west of Max Meadows.

The next well known period of disturbance, marked *B*, occurs near the top of the Shenandoah limestone, and it has been referred to in this paper as being characterized by limestone conglomerate throughout a wide area, and particularly so on Stony creek, Giles county. Limestone conglomerates at or near this horizon are known all along the eastern edge of the valley across Tennessee, but have never been described. In Georgia and Alabama a conglomerate at this horizon covers a large extent of country and has been briefly described by C. W. Hayes.†

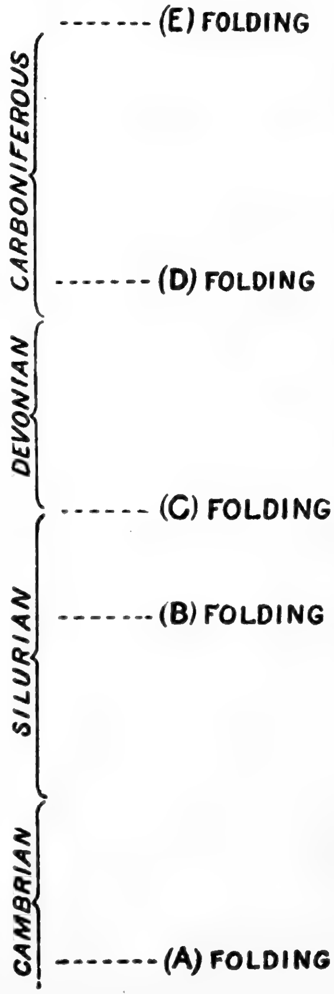


Figure 1.—*Determined Periods of Appalachian Folding.*

General stratigraphic Column showing their approximate Positions and roughly indicating their Occurrence in Paleozoic Time.

The main period of deformation, marked *C*, treated of in this paper is the one which folded the limestones and produced the structural basins

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* Phil. Soc. of Washington, Bull., vol. xii, pp. 77–88. Arthur Keith: Geology of Chilhowee Mountain in Tennessee.

† Geological Survey of Alabama, Bull. no. 4. Report on the Geology of Northeastern Alabama and adjacent portions of Georgia and Tennessee, pp. 42–43.

described. So far as the evidence of these basins is concerned, this folding must have occurred previous to the deposition of the Walker black shale, but which in a general way will be regarded as occurring at the beginning of the Devonian period. This is doubtless the same disturbance recognized by N. H. Darton in the vicinity of Staunton, Virginia,* which produced the unconformity between the Oriskany sandstone and Lower Helderberg limestone.

The uplifting and probable folding, marked *D*, which closed the sedimentation in Price mountain basin, has not heretofore been recognized; this must have occurred near the middle of the Lower Carboniferous period. There is considerable evidence in the northwestern portions of the valley, in the vicinity of New river, of the continuation of this period of disturbance throughout the deposition of the Mauch Chunk sediments, but the evidence is not in shape for presentation at this time.

Lastly, the post-Carboniferous period of folding, *E*, has long been considered as the only one and accountable for all of the folding of the Appalachian type that exists in this portion of the continent. It now seems as though this was no more important than many which preceded it and that, in fact, the deformation has been practically continuous since early Paleozoic time.

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*Notes on the Stratigraphy of a portion of Central Appalachian Virginia: Am. Geologist, vol. x, pp. 10-18.

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# PALEOZOIC INTRA-FORMATIONAL CONGLOMERATES *

BY CHARLES D. WALCOTT

(*Presented before the Society December 28, 1893*)

CONTENTS.



## INTRODUCTION.

Usually the presence of a conglomerate in a stratigraphic series of rocks is a matter of considerable importance to the geologist. He naturally infers the presence of a break in the continuity of sedimentation; an orographic movement of greater or less extent; erosion of a prëexisting formation. He sees, in his mental review, the waves sorting and depositing sand, pebbles and bowlders derived from the uplifted land. The idea of the lapse of a period of time of considerable and often long duration is formed as he recalls orographic movement, erosion and unconformity of deposition. If the conglomerate is near the base of some formation or series of formations, he views it as almost conclusive evidence of the marked change that introduced the new deposits. This is all fair induction from observed facts, and it is the general and approved experience of geologists. When I ventured to describe to a veteran geologist the peculiarities of a formation of conglomerate that occurs in the Lower Cambrian rocks of the eastern United States he advised my reviewing my field work and opinions, as the latter were unusual. This

* Printed by permission of the Director of the U. S. Geological Survey.

has been done and observations extended, with the result that I find the presence of intra-formational conglomerates a not uncommon phenomenon, one that must receive the attention of every field geologist working in the Appalachian region, from the Saint Lawrence valley in the northeast to the Cretaceous boundary of the Paleozoic of the far southwest in Georgia and Alabama.

Care is to be taken that intra-formational breccias are not confused with the intra-formational conglomerates. The former have a wide geographic distribution, and owe their origin to local disturbance within the beds affected, without presupposing elevation above sealevel and erosion.

## Intra-formational Conglomerates.

*Definition of Term and Illustration.*—An intra-formational conglomerate is one formed within a geologic formation of material derived from and deposited within that formation. An illustration occurs in the old limestone quarries on the east shore of the Hudson, below Schodack landing, Rensselaer county, New York. The section is formed of thinly bedded limestone, carrying the typical Olenellus fauna. Toward the summit of the quarry a band of conglomerate limestone rests conformably on the bedded limestone. Pebbles and fragments of several varieties of limestone occur, in which fragments of typical species of the Olenellus fauna were found. The conglomerate band varies in thickness from 2 to 6 feet, and it is capped by thinly bedded limestones that carry the same species of fossils as the limestones beneath the conglomerate and the bowlders in the conglomerate. It shows that the limestone pebbles, bowlders and brecciated fragments were formed from a calcareous sediment sufficiently consolidated to be broken up, more or less rounded by attrition and collected to form a bed of conglomerate, the matrix of which is usually calcareous. This section clearly proves the formation of conglomerate within the Lower Cambrian terrane, the materials of which were derived from limestones deposited during Lower Cambrian time.

The conglomerate at the locality described is not as clearly marked as some in the Lower Cambrian terrane of Lancaster and York counties, Pennsylvania, and in the conglomerates at the base of the great Ocoee series of Tennessee. The limestone conglomerates of the Cambrian and Ordovician of the Saint Lawrence valley are not typical illustrations of true intra-formational conglomerates, but I shall speak of them, as they appear to have been formed under somewhat similar conditions.

*Canadian Localities.*—Sir W. E. Logan has graphically described the limestone and conglomerates of the south shore of the Saint Lawrence at Trois Pistoles, Bic, Metis, the vicinity of Quebec and the west coast of


CONGLOMERATE LIMESTONE

QUARRY ONE-FOURTH OF A MILE NORTH OF STONER'S STATION, YORK COUNTY, PENNSYLVANIA.

Newfoundland.* During the summer of 1889 I had an opportunity to examine the sections of the Ordovician and Cambrian rocks in the vicinity of Quebec, and I was very much impressed by the mode of occurrence of the limestone conglomerates. The lowest bed of conglomerate occurs in the Sillery shales, on the south shore of the Saint Lawrence below Levis, and on the south shore of the island of Orleans. The limestone bowlders show transportation, and are mingled with pebbles of quartz, sandstone, et cetera. The Olenellus fauna occurs abundantly in the fragments of limestone, but the source of the limestone is unknown. It is, however, of Cambrian age, and it has been redeposited about 1,500 feet from the summit of the series of shales, sandstones, et cetera, that are referred to the Cambrian.†

The lower bed of limestone conglomerate at Point Levis occurs near the base of the Ordovician, in the Point Levis shale. It is made up of large and small bowlders of limestone, carrying the Upper Cambrian fauna, that are embedded in the limestone matrix in which occurs the typical Calciferous fauna. The matrix is a hard, gray, impure limestone which forms solid layers that were traced for over 500 feet on the strike. As in the case of the limestone bowlders carrying the Olenellus fauna, the origin of the bowlders carrying the Upper Cambrian fauna is unknown, as no beds of limestone of a similar character have been found in the Sillery shales upon which the Ordovician shales and interbedded conglomerate rest. The matrix of the conglomerate proves the formation to be of lower Ordovician age. In a bed of limestone fifty feet higher up in the section I found additional species of the Calciferous fauna, and in a bed of limestone conglomerate above this the fossils in the bowlders and in the matrix as well are of Calciferous age. In a search of two days I failed to find a Cambrian fossil at this horizon, although such an occurrence might be anticipated from the occurrence of the older limestones in the conglomerates beneath. This second band of conglomerate in the Levis series appears to be a true intra-formational conglomerate. The limestone conglomerates embedded in the shales and shaly limestones beneath the city of Quebec are of much less stratigraphic importance than are those at Point Levis; but the same conditions of deposition appear to have existed during the formation of these rocks of middle Ordovician (Chazy-Trenton) time.

*Vermont and New York Localities.*—In the passage beds between the Cambrian and Ordovician east of Highgate springs, Franklin county, Vermont, layers of limestone conglomerate occur, some of the fragments of which carry the lower Ordovician fauna. The horizon of the con-

* Geology of Canada, 1863, pp. 227, 260–261.

† Am. Jour. Sci., vol. xxxiv, 1890, pp. 112–113.

glomerate appears to be within the range of this fauna, and points to an intra-formational origin.

The type that has already been described as occurring at Schodack landing, New York, has been observed at many localities to the north, in Washington county, New York, where it is a common feature of the Lower Cambrian terrane.

*Pennsylvania Localities.*—The succession of Cambrian rocks in York and Lancaster counties, Pennsylvania, is very clearly defined. A massive quartzite is succeded by shales, and then a massive bedded, more or less silicious limestone that varies in color and composition in its several beds. This massive bed of limestone is succeeded in numerous instances by beds of limestone conglomerate which are interbedded in more or less thinly bedded, somewhat shaly limestones. One of the most clearly defined sections is exposed at Bellemont, Lancaster county, on the line of the Pennsylvania railroad. The massive blue and white Cambrian limestones are succeeded by a few feet of a blue, earthy limestone and shale, and upon this there is a bed of limestone conglomerate, from eight to ten feet in thickness, that is made up largely of pebbles and bowlders of limestone derived from the limestone beds beneath. A second bed of conglomerate is seen on the roadside to the north.

About 40 miles west of Bellemont, at Stoners station, on the York and Wrightsville railroad, York county, Pennsylvania, an extensive exposure of the Lower Cambrian limestones and conglomerate is beautifully shown in an old quarry just east of the wagon-road, one-fourth of a mile north of the railroad track. Alternating bands of thinly bedded limestone and massive beds of limestone conglomerate form about 100 feet of the exposed section, in which five beds of the conglomerate limestone are well shown. The basal bed has a fine grained, gray limestone matrix with brecciated limestone fragments in it which range in size from that of small shot to masses three feet in diameter. These pebbles and bowlers vary in lithologic character, some resembling the matrix and others being oolitic, arenaceous, semi-marbleized and shaly limestones. The thinly bedded limestones separating the conglomerate bands are from four to six feet in thickness, and are very clearly defined.

In the second band of conglomerate the larger bowlders occur in the lower portion. The other three beds vary in details, but they are all formed of the same type of rock. One of the upper beds contains a multitude of small fragments of limestone. It was impracticable to obtain a photograph of the basal beds, which contain the largest bowlders. Plate 5 illustrates the evenly bedded limestones above and beneath the third band, and also shows the character of some of the limestone bowlders. In the shaly limestone at the base of this bed a large bowlder,

BOWLDERS IN THIN BEDDED LIMESTONE BETWEEN BEDS OF CONGLOMERATE.
QUARRY ONE-FOURTH OF A MILE NORTH OF STONER'S STATION, YORK COUNTY, PENNSYLVANIA.

two feet or more in diameter, is entirely embedded in the shaly limestone. This bowlder, as shown in plate 6, was evidently deposited on the bed of the sea and the calcareous mud gathered quietly about it. At about the same horizon, in a quarry on the east side of York, a massive bed of limestone conglomerate is beautifully shown. A photograph of it is reproduced as plate 7.

The quartzites, shales and limestones beneath these beds of conglomerate are known to carry the Lower Cambrian or Olenellus fauna; and the same fauna, with the exception of details of variation of species, occurs in the limestones and shales above the conglomerates, thus placing the latter within the definition of intra-formational conglomerates.

*Virginia Localities.*—Mr M. R. Campbell* informs me that in the vicinity of Radford, Virginia, there is a formation that appears to be a true intra-formational conglomerate. He states that it is in the great Cambro-Silurian limestone, and consists of a yellowish white, chalky limestone matrix, in which are embedded rounded fragments of limestone that are similar in composition to the matrix, and that can only be distinguished from it with difficulty. A few small grains of foreign material were observed. The exact stratigraphic horizon could not be determined, owing to the complexity of the structure and the poor exposures. Two miles below Radford the actual contact was observed between the conglomerate and the bedded limestone, where the former rests on the cut edges of the folded limestones beneath. Mr Campbell believes this indicates shore conditions, contortion of the limestone deposits and their elevation above sealevel, to form cliffs that supplied material for later beds of the same great formation.

Another case of this kind was observed by Mr Campbell at a horizon northwest of Bristol, Virginia. He found that here the conglomerate occurs in a bed of shaly limestone, but a few feet thick, that belongs in the Nolichucky (Cambrian) shales. This bed appears to have been broken up largely into flat fragments that were quite well worn on their edges, and then redeposited in the same bed and cemented into a solid mass of limestone. The peculiar feature of this deposit is its extreme thinness and the apparent freedom from all marks of erosion. It is quite persistent and no evidence of an unconformity was observed.

*Tennessee Localities.*—The intra-formational conglomerates already described have been identified as such by the presence of similar fossils in the bowlders of the conglomerate and the superjacent and subjacent bedded limestones. Those about to be described are identified entirely by lithologic characters. These, however, are so clearly defined and are

*Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia: Bull. Geol. Soc. of Am., vol. 5, pp. 175–176.

of such variety that the conclusions based upon them are considered to be nearly as reliable as those where fossils are present.

In Tennessee these conglomerates occur in the lower portion of the Ocoee terrane of Safford. Mr Arthur Keith named the basal slate the Wilhite. This slate rarely exceeds 700 feet in thickness, and it is capped by the silicious Citico conglomerate (Keith). Within the Wilhite slate, especially in the upper 200 feet, and along its strike for over 100 miles, numerous beds of limestone occur. Usually a limestone conglomerate is found in the same section, generally above the bedded limestone. These limestone conglomerates have been cited as proof that the Wilhite slates were of later age than the Ordovician limestones, which were assumed as having furnished the pebbles and bowlders of the limestone conglomerates and hence that the Ocoee terrane instead of being an older formation than the great limestone series of Tennessee was of later date, and hence of post-Ordovician age.

In company with Mr Keith I visited numerous localities of the Wilhite slate in Cocke, Sevier and Blount counties. At a locality three miles south, 65° east of East Fork, Sevier county, a limestone conglomerate occurs by the roadside and also on the north side of the road on Stephen Huff's farm. The bedded limestones vary in texture and color and in the presence or absence of more or less arenaceous material, but the weathered surfaces of many of the beds are very characteristic. At the locality by the roadside there is little, if any, of the bedded limestone exposed, the conglomerate resting on the calcareous shale or slate containing compressed lentiles of impure bituminous limestone. The conglomerate is formed of brecciated and rounded pebbles and bowlders of limestone and, more rarely, of a fine grained sandstone. The limestone bowlders vary in lithologic characters from pure white limestone to sandy and silicious and their various combinations. In color, they are blue, gray, black, purple, white, pinkish, dove, etcetera. About two miles to the north of this locality, on Wilhite creek, there occurs a somewhat similar conglomerate, in which the limestone bowlders reach a diameter of from three to four feet. A peculiarity of the conglomerate at these places is the presence of large bowlders in the slate above the main body of the conglomerate.

At a locality two miles east of Jones cove, Sevier county, an interesting phase of the conglomerate is the presence of bowlders of a dark, sandy limestone embedded in the mass of the bedded limestone that occurs below and also above the conglomerate. The matrix of the conglomerate is frequently largely made up of a sandy limestone of the same lithologic aspect as the bedded limestones out of which were made the bowlders of the conglomerate. The limestone conglomerate was also

LIMESTONE CONGLOMERATE IN LOWER CAMBRIAN LIMESTONE.
QUARRY ON EAST SIDE OF YORK, PENNSYLVANIA.

noted at a locality three miles south of Del Rio, Cocke county, where it occurs above the limestone in the Wilhite slate.

One of the best localities to study the relations of the limestones and conglomerates is on the north side of the entrace to the narrows of the Little Tennessee river, in Blount county. Here the bedded limestones in the Wilhite slates are beautifully exhibited, and above them the limestone conglomerate is strongly marked, and bowlders of the limestone over six feet in diameter occur in the lower portion of the Citico conglomerate. Another peculiarity at this locality is that the limestones within the Wilhite slate were broken up and many of the fragments rounded to form a bed of conglomerate just above the horizon of the limestone beds from which, elsewhere, they were derived, and that the same process was repeated with the bed of conglomerate. We found, in an upper bed of conglomerate, bowlders formed of masses of conglomerate of the same character as in the stratum some distance below in the section. In this upper conglomerate numerous quartz pebbles of the same character as those of the Citico conglomerate are embedded in the limestone matrix. Special effort was made by both Mr Keith and myself to discover evidences of the presence of limestones of a different character from those found conformably bedded in the Wilhite slate, but without success. The limestones of the Wilhite slate are so marked in their lithologic characters and the bowlders in the conglomerates have lithologic characters so similar that we did not hesitate to refer the source of the material of the latter conglomerate to the limestone beds within the Wilhite formation. At one locality, two miles south 10° west of Sweetwater, Cocke county, a sandstone rests unconformably upon the Knox limestone and contains rounded pebbles of the limestone carrying the characteristic fossils which are embedded in the limestone beneath the sandstone. This sandstone occurs in the isolated outcrop, and is not known to be of Ocoee age.

*Origin.*—The relation of the bedded limestones to the superjacent conglomerates proves that the calcareous mud which was subsequently consolidated into the limestones solidified soon after deposition. This is shown by the presence in the conglomerate of rounded pebbles and angular fragments of limestone with sharp clear cut edges. The presence of the conglomerates above the limestone beds, from some portion of which they were derived, leads me to believe that the sea-bed was raised in ridges or domes above the sealevel and thus subjected to the action of the seashore ice, if present, and the aërial agents of erosion. From the fact that the limestones upon which the conglomerates rest rarely if ever show traces of erosion where the conglomerates come into contact with them, the inference is that the débris worn from the ridges was

deposited in the intervening depressions beneath the sea. In the case of the conglomerates of the Wilhite slates of Tennessee it is exceptional to find a bedded limestone above them; but within the Lower Cambrian of Pennsylvania and New York the conglomerates are interbedded in the limestones.

Large bowlders of limestone were observed in the Wilhite slates on Wilhite creek, Tennessee, above the main conglomerate bed, and large bowlders of limestone were observed in the bedded limestones at Stoner's quarry, Pennsylvania. The mode of occurrence of these bowlders, especially those in the limestones at Stoner's quarry, leads to the view that they may have been dropped upon the sea-bed from floating ice. No other explanation occurs to me that will account for the transportation of a bowlder from the shoreline and the placing of it upon the sea-bed so as not to disturb to any marked degree the sediment then accumulating. In the special example at Stoner's quarry two feet of calcareous mud was deposited in thin layers about the bowlder and as much more above it before the introduction of conditions that deposited the next stratum of conglomerate.*

The history of Appalachian sedimentation and mountain-building proves that a more or less constant movement was taking place from Algonkian time to the close of the Paleozoic. This movement was at times greatly prolonged and resulted in marked topographic features. More frequently the minor movements produced local effects, and some of them resulted in the formation of the conglomerates described.

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* Sir William Dawson says that the "only means of explaining these conglomerates [Quebec, Point Levis, Metis] seems to be the action of coast ice, which at this period appears to have been as energetic on the American shores as at the present day, and seems to have had great reefs of limestone, probably in the area of the gulf of Saint Lawrence, to act upon and to remove in large slabs and bowlders, piling these up on banks to constitute masses of conglomerate." Quart. Jour. Geol. Soc., London, November, 1888, pp. 809, 810.

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# PLEISTOCENE DISTORTIONS OF THE ATLANTIC SEACOAST

BY N. S. SHALER

(*Read before the Society December 28, 1893*)

CONTENTS



## Evidences of orogenic Action.

More than once I have called attention to the fact that the Tertiary and Cretaceous beds on the island of Marthas Vineyard, Massachusetts, show throughout an area of about fifty square miles unmistakable evidence of mountain-building stresses. The strata, having an aggregate thickness of certainly many hundred, perhaps of some thousand feet, have been thrown into folds of considerable amplitude, which are so sharply compressed that the numerous outcrops show dips which average more than 45°. The suggestion that these distortions have been produced by the shearing action of the ice in the last glacial period is completely disproved by the very well developed preglacial topography which this region exhibits—contours of hill and dale which were formed in these soft rocks after they were folded, and on which the drift rests as an incomplete mantle. It is impossible to conceive that the folding of the rocks could have been accomplished without the complete destruction of the previously existing topography.

Recently my colleague, Mr J. B. Woodworth, has examined the similar distortions of Block island. He informs me that in general character they closely resemble those of Marthas Vineyard. While the horizon of these Block island beds is not as yet clearly determined, the evidence goes to show that they are in part, at least, of Pleistocene age; they also have preserved their preglacial topography, which is only partly masked

by the drift, showing that here also the hypothesis of glacial shoving cannot be reasonably advanced to account for the distortion of the strata. Accepting these indications as evidence of orogenic action at a comparatively recent time, the question is as to their relation to the other movements along the Atlantic coastline.

## Extent, Duration and Character of the Movements.

It seems in the first place evident that the Atlantic coast from South Carolina northward to the Saint Lawrence has been the seat of recurring mountain-building action since the Triassic time. These movements, in so far as we can clearly determine them, have not operated in the country south and west of this district. The distortions which flexed the Triassic or Rhetic deposits appear to have occurred in the Jurassic time, or at least before the deposition of the Cretaceous. The last named period seems to have passed, as did the division of the Tertiary, without the action of the mountain-building forces being manifested. At the end of this period, but long enough before the glacial epoch to permit the development of a complete topography, with wide valleys and low, arched hills, came the folding and faulting which has dislocated the beds in southeastern Massachusetts.

It seems tolerably clear that this New England disturbance was not local, though its particular manifestations are peculiar. The action of the same forces, though operating in a somewhat dissimilar manner, is traceable southward along the coast, as has been shown by the studies of McGee and others, on the faulting which is there developed. The continuation of these breaks to the northward in foldings rather than in faultings finds its parallel in what we observe in the movements which occurred in the interval between the deposition of the Carboniferous and the period of the Trias. In the eastern Tennessee district we find the displacements effected, in the main, by faulting; in southwestern Virginia the folds become more common, and thence northwardly they increase in relative importance until the dislocations disappear in a series of small but characteristic anticlines in the region near Catskill, New York.

These dislocations along the Atlantic coast seem to indicate, especially when taken with those which distorted the Triassic beds, that this shore was the seat of mountain-building work long after it apparently had ceased in the more interior portion of the Appalachian system. So far as they go, they afford additional evidence that a coastline is nominally the seat of orogenic work.

The Marthas Vineyard foldings appear to be the most recent of any well developed anticlines in the eastern portion of the United States.

I know, indeed, of no other field where rocks of an age so near the present indicate such extreme compression. Their occurrence appear to show a considerable renewal of the mountain-building forces in a district which by its profound degradation seems to have been long exempt from such accidents. It is an interesting question whether the strains which created these folds have quite spent their force. So far as the evidence from the fields in which they occur is concerned, it is clearly to the effect that no movement has taken place since the preglacial topography was developed. I have made a careful study of the areas where the glacial drift is so thin that it does not hide the contours and where the erosion effected by the ice seems to have been insignificant, and can find no trace of any postglacial deformations. The stresses, though they were evidently very great, appear to have been effectively discharged by the crumplings of the strata which they created.

The question as to the nature of the orogenic movement which gave rise to the folds of southeastern Massachusetts is interesting. On the mainland, less than 20 miles away, the ancient gneisses and other highly crystalline rocks afford the foundation for the relatively recent strata. This fact, as well as the general character of the geology along this portion of the Atlantic coast, makes it probable that the Cretaceous and the Tertiary series of the islands rest on very massive deposits. We note also that the glacial erosion which has been effected on the bottoms of Buzzards bay and Vineyard sound has not brought into the Vineyard moraine materials from any other than crystalline rocks, except relatively small fragments, which we can trace to the Narragansett basin. It is difficult to conceive that the foldings of the beds exhibited at Gay Head and elsewhere in this district are the results of similar anticlinals and synclinals formed in the massive rocks on which they lie or which must at least be not far beneath them.

### Origin of the Movements.

An explanation of the method in which these foldings of Cretaceous and Tertiary strata has been effected is perhaps indicated by the conditions in the Richmond, Virginia, coal basin. In that field the Mesozoic rocks have been thrown into sharply dislocated masses by the formation of a synclinal, developed in the crystalline rocks on which they lie. Such a trough in massive beds may be formed in large measure by faulting, though the hypothesis of folding as well is not excluded. It is true that in the Vineyard district there is no visible indication showing the seaward side of such a trough as this suggestion calls for. It should, however, be observed that the crests of the ridges of crystalline rocks which are found along this shore decline rapidly seaward, so that the outer rim

of a basin might well be below the ocean-level. It should also be noted that the gneissic rocks along the mainland from New Bedford eastward decline in steep slopes beneath the sea in the manner which we should expect if they represented the margin of a synclinal trough.

In conclusion, it may be remarked that the orogenic movements of southeastern Massachusetts evidently occurred shortly after a very extensive importation of detritus into the district took place. The exposures at Gay Head and elsewhere show that a thick section was deposited with great rapidity. At no other point on the Atlantic coast of this continent do I know of a case where such a great mass of sediments has been accumulated in a similarly brief period. It is therefore interesting to see that this change of burden was followed by a period of dislocation. The facts, in a word, seem to confirm the hypothesis that transfers of sediments tend in some way to excite mountain-building actions.

## No Evidence of massive Elevation.

It is important to note the fact that notwithstanding the large amount of crumpling which has taken place in the Marthas Vineyard section, the beds have not been subjected to much massive elevation. They were evidently formed in positions very near the level of the sea. They are still in a general way at about the same position. Similar data concerning other formations indicate that this portion of the continent has at several stages in its development been at about its present height above the ocean. Some of the lower Cambrian beds of Attleboro, Massachusetts, contain abundant pebbly waste, which apparently was deposited in rather shallow water. The conglomerates of the Roxbury series, which are presumably of Potsdam age, are clearly coastal deposits. The Carboniferous series of the Narragansett basin was also formed near the sealevel. The intermediate periods doubtless saw great changes in the altitude of the surface in this southeastern district of New England, but the facts seem to show a tendency of the land to return to the level which it has at present.

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# RELATION OF MOUNTAIN-GROWTH TO FORMATION OF CONTINENTS

BY N. S. SHALER

*(Read before the Society December 28, 1893)*

CONTENTS



*Introductory.*—In this writing I wish to call attention to certain features in the distribution of mountains which seem to me to throw light on the conditions which lead to the development of continents, and, as the points to be set forth concern a considerable range of phenomena, I shall state them briefly, with the expectation that in some other form of publication the chance may be offered for more extended presentation.

*Limitations as to Position of Mountains.*—Mountains appear to be limited to the continents or to large islands which are more or less continental in their relations. This is shown by the fact that the surfaces of the greater oceans are essentially destitute of islands which we can suppose to be mountain-tops which have attained the surface of the water. All the thalassic islands, in a word, are volcanic masses or have been brought to the surface by the coral-building animals. As the average depth of the sea is about fifteen thousand feet, and as there are some hundred peaks in various systems which attain to more than this height, we should expect, if mountains grew on the sea-floor as freely as they do on the land, to find more of these elevations in that realm than we do on the continental areas. The case is even stronger when we consider that on the land mountains are continually subjected to erosion, an action to which they would not be exposed in the oceans until they had risen above the surface of the water. Although we may recognize the fact that down-wearing is a concomitant and perhaps a necessary condition of extended dislocation of strata, and that mountains never have had

the topographic relief which would be given them by restoring the strata which once overarched their summits, we may still believe that if they developed on the ocean-bottom as they do on the great lands they would attain on the average their greatest elevation in the sea. We may therefore assume that there is some causal relation between the growth of continents and the dislocation of strata which occur on them.

*Origin and Occurrence of Mountain Pedestals.*—Some years ago, with these points in mind, I studied the Italian peninsula, making, partly in the field and partly by maps and reports, several sections across its surface from the Adriatic on the east to the Tyrrhenian sea on the west. I chose this peninsula for the reason that its geology is fairly well known, as is also the shape of the sea-bottom on either side of the land. An inspection of this area convinced me that, along with the folding and other compressive phenomena which here produced the mountain-axes of this district, there has been a progressive uprising, in a massive way, of the deposits which form the outer part of the earth, and that this basilar uplift extends for a considerable distance on either side of the much distorted areas. Such a foundation uplift or pedestal occurring in mountain-building has long been noted, but its full and true import seems not to have been recognized. It appears clearly to indicate that during the process of folding and the concomitant faulting there is a widespread movement of the underlying rocks toward the seat of disruption. This material, which is set in motion by the orogenic forces, not only serves to underpin or support the arches of the strata, but accumulates in the neighboring subjacent regions in such amount as to uplift the surface of the earth in the form of a broad belt, on which, at the end of the process, the mountains lie as sharp ridges.

It is obvious that in many cases the pedestal or highlands, where the strata are not distorted, which lie on one or both sides of many mountain-ranges is often in part due to the thickening of strata, brought about by the supply of sediments that the elevations have afforded to the seas at their feet. Making allowance for this source of error, I think it is still evident that the pedestal feature is a normal element in mountain-growth.

On the continent of North America we discern three great systems of elevation, two of which, the Cordilleras and the Appalachian, show the more or less degraded remains of the basilar uplifts, which were here produced during the development of the axes. The central trough of this land, so far as it is occupied by the Mississippi valley, is substantially composed of the slopes which lead down from the great systems on the east and west. The Laurentian system shows less of this pedestal feature, probably because it was to a great extent destroyed during the ages which elapsed between its formation and the deposition of the strata which we trace into contact with its ancient ridges.

A similar, though more obscure relation between the growth of mountains and the upheaval of the non-folded districts about them is traceable in Europe, and apparently exists in all the continental fields. Thus, as in America, we note that the mountains are bordered by relatively high lying tablelands, and that the altitude of the whole field depends, in large part at least, on the movements of underearth materials toward the axes of disturbance by folding.

The amount of this inner earth-matter which has moved toward the mountain-built sections of the land cannot, in the present state of our information, be well computed. It seems to me, however, that much of the height of the continents, perhaps nearly the whole of the upliftings which serves to retain its masses above the plane of the ocean, may be attributed to this subterranean migration of rocks. If this view be correct, then we should regard the continents, at least so far as their history as dry lands is concerned, as in great part the product of mountain-building forces. In this work the primal action is the movement of rock materials toward the axes of disruption and the consequent elevation of the region where the movements occur. In a secondary, yet important, manner the process of erosion removes a portion of the highlands, distributing the waste in a measure over the surface of the pedestals, thereby increasing their elevation on the flanks of the range. There are thus two contrasted movements of the materials involved in mountain-building—in the interior, toward the centers of elevation, and on the surface, away from those upland districts.

*Causes of Mountain-uplifting above Sealevel.*—Although the process of mountain-building may account for the growth of continental areas it cannot be used to explain the process which brought the uplifted areas of the earth above the ocean-level. As before noted, the evidence derived from the distribution of these elevations leads us to the conclusion that they do not develop in the depths of the seas. It appears to me, however, that from the recent extension of our knowledge concerning the configuration of the sea-floors we may discern certain features there which perhaps seem to account for the uplifting of the continental arches to the water-level. At various points on the ocean-bottom we note the existence of broad ridges which rise five. ten, or even fifteen thousand feet above the deeps which lie about them. There is such a ridge in the middle of the Atlantic, and another less distinct, perhaps because less well known, in the southern division of that ocean. In various other districts there are indications of similar broad uplifts, though the progress of our knowledge concerning the topography of the sea-bottoms has not as yet enabled us to trace their forms in a clear way.

It seems to me a fair hypothesis that the formation of a great land-area began by the elevation of one or more of these submarine ridges above

the level of the sea. When the process of uprising brought the fold into the realm of erosion, the irregular wearing of the mass began those changes of burden to which we have learned to look for the immediate determination of mountain-building action. Thenceforth the organization of the land as regards its shape appears to have depended mainly in the localization of the migrations of earth-matter brought about by the orogenic forces. It is evident, however, that this migration began with the subaqueous history of the fold, and that the land distortions of strata has served the important end of determining the supermarine form of the area.

The rise of submarine folds from the depths of the sea to the air is indicated in the geologic features of this and other continents. Instances of this nature are seen in the peninsulas of Florida and Yucatan, in the Antilles, and in the old ridge known as the Cincinnati axis. In the first mentioned district a fold of the sea-bottom having a length of about 600 miles appears to have risen from a depth of about 5,000 feet. As yet the process of erosion has not determined distinct axes of fracture on the crest of this ridge, though there are some signs of such displacements. The peninsula of Yucatan appears to represent a similar process of upward growth of a fold which has not yet been mountain-built. The Antilles seem to afford an instance of a lofty, narrow ridge which has risen from a great depth and to have developed on its crest an extended mountain system. The Cincinnati axis, a low ridge having about the length of Florida, was formed in the middle Paleozoic seas, beginning to attain the water's surface in the early stages of the Cincinnati group. The crest of this broad elevation bears the marks of the mountain-building forces, but the age of these dislocations is not certain.

*Conclusions.*—It is true the cases in which we note the unlifting of folds of the ocean floor which have attained the sealevel involve relatively small areas as compared with the continental fields, yet when we trace the history of this and other continents back to the time when they were beginning to take shape, we find that the conditions indicate the masses to have been relatively much smaller than they are at present. It seems that, given a case where an elevation of the sea-floor attained the surface, the facts warrant us in supposing that the process of mountain-building would begin as soon as locally intensified erosion and deposition occurred; this would induce a further migration of interior materials toward the fold, thus favoring its greater elevation. If this be the case the earth folds may, as regards their history, be divided into two groups: those which fail to attain the surface of the sea and are not subjected to the stimulus to further growth which mountain-building seems to bring about, and those which, attaining the condition of land, are by the process of erosion led to a rapid upward development.

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# PHENOMENA OF BEACH AND DUNE-SANDS

BY N. S. SHALER

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CONTENTS



## BEACH-SANDS.

### *VALUE OF THEIR INVESTIGATION.*

The following notes concerning certain phenomena of beach and dune-sands have an interest for the reason that they seem to explain some of the conditions under which the arenaceous materials of the seashore journey before they come to rest in stratified deposits. Incidentally they show some facts as to the part which the coastal sands take in protecting the shore from the action of the sea. These observations are the result of work done on the eastern coast of the United States in connection with the tasks which have fallen to me as geologist of the Atlantic Coast Division of the United States Geological Survey.

### *RESISTANCE TO ABRASION.*

One of the most noticeable features which is exhibited by beach sands is their extraordinary endurance of the beating of the waves. On examining any pebbly beach exposed to the ocean-surges we readily perceive that the masses of stone wear at a very rapid rate. Thus, at cape Ann, cubes of granite of a kind which forms excellent blocks for city pavements are, when exposed to the surf, worn in the course of a year to spheroidal forms, with an average loss of more than an inch from their peripheries. Experiments with fragments of hard burned brick have shown me that in a year of moderate beach-wearing they may be reduced by the abrasion to half their original size. On the other hand the sand derived from these pebble-beaches endures for an unlimited time, evidently with little wearing. Though subjected for ages to the beating of the waves, with perhaps a hundred times as much energy applied to the surface of which it forms a part as would suffice to reduce a granite-bowlder containing a cubic foot of material to a granular or powdery state, the beach sands remain unworn.

An excellent example going to show the endurance of sand-grains on the shore is afforded by the beaches of the Atlantic coast from New York southward to near cape Florida. Collections along this line show that the waste from the northern part of the coast is slowly journeying southward, partly along the beach-strip and partly in the shallow water at a little distance from the shores, yet when these sands arrive on the southern coast of Florida, though their quartz grains are somewhat rounded, they are not much smaller than those on the region of the coast about cape Hatteras.

### *CAUSE OF THEIR ENDURANCE.*

On examining the conditions of the sand on a wet beach we find the reason for the slight amount of wearing to which the grains are subjected from the action of the waves. Owing to the small size of the fragments and to the fact that they are generally provided with angular faces a film of water is held by capillarity between the adjacent bits so that they, so long as the beach is full of water, do not touch each other. Thus the blow of the waves is used up in compressing the interstitial water and is converted into heat without wearing the mineral matter in an appreciable degree. A simple experiment will illustrate the extent to which the water is held between the wet grains. By pressing the foot on the surface of a flat sand beach just above the waterline we may observe that the sand usually whitens around the field of pressure, the change in hue

being due to a partial expulsion of the water; on withdrawing the weight the sand resumes its original color.

Those who will observe the condition of the water along a pebble-beach in times of heavy rains may readily note the fact that it contains a considerable amount of mud derived from the grinding action of the stones as they are drawn over each other by the surf. A similar observation made on a normal sandbeach will show that the fragments yield no waste.

*PROTECTORS FROM CONTINENTAL DESTRUCTION.*

Important geologic consequences arise from this peculiar feature in the action of sand on the seashores. To it, in the main, is due the very effective protection which sandbeaches afford the land areas against the assaults of the waves. Probably more than four-fifths of the shores of the continents which face the open sea are thus protected from the surges by finely divided rock-material. If the agents of wear could deal with the masses of these tiny fragments as easily as they do with rock-cliffs, the history of our continents would have been quite other than that which we trace. The shores, especially those composed of friable materials, would have been easily driven back into the land. As it is, the waves, not being able to grind up the sands, have to deposit them in deep water or in embayments of the shore before they can continue to erode the cliffs which yield the detritus.

Those who have examined the condition of small islands may have remarked the fact that sandbeaches are rarely found along their shores, the reason being that the limited field of erosion is not likely to afford a sufficient supply of the material to make considerable accumulations of that nature. It is partly, at least, in consequence of this lack of sand-barriers that small islands are generally in a process of relatively rapid shore-erosion, the rate of this destruction being in most cases evidently greater than it is on the mainlands.

*SOME SOURCES OF SUPPLY.*

*Seaweeds.*—As the supply of sand on the shores is a matter of much consequence in determining the effectiveness of the wave-action against the land, I venture to note, in passing, two ways in which the deposits of the shore line are augmented. The first of these is effected by a peculiar action of our larger seaweeds. These plants have the habit of attaching themselves to a pebble or shell, it may be, in water so deep that the waves can have no scouring effect on the bottom. As they grow, these plants gradually expose so much surface to the waves and are so upborne by their air vesicles that in the end they often pull the body to which

they are attached from its place on the floor; it is then quickly urged by the surges to the beach. Attaining this position, it is at once stripped of the plants which bore it ashore.

On the beaches of eastern Massachusetts a mile of ocean front, in a time of heavy storms, often receives in the course of a day from ten to twenty tons of pebbly material, borne in by seaweeds. In some cases the rate of the importation much exceeds this amount. The pebbles thus delivered to the shores are not infrequently from three to six inches in diameter. Where pebbles do not abound on the bottom, as is the case along most sandy shores, the shells of the larger mollusks are in the same way uplifted and brought upon the beach.

*Floating Pumice.*—A certain contribution of débris to the seabeaches, the amount of which is not yet determined, arises from the stranding of floating pumice. Observations which I have made on the shores from Eastport to Key West show that every part of this coastline receives a certain share of this volcanic matter. On the Florida shore the quantity of the material appears to be much greater than elsewhere, this probably because of the strong and far journeying current which passes by that promontory. On this part of the coast it appeared to be easy at certain points on the strand to gather an identifiable bit of pumice in each square yard. As we go to the northward, passing away from the margin of the Gulf stream, these pumiceous fragments become much more rare until on the New England coast it may require a careful search to reveal a bit of the material.

Owing to the frail nature of pumice, as well as to the chemical unstability of its composition, it appears rapidly to break up; it is thus not easy to determine what part of the beach-matter is from this source. Inasmuch as these volcanic materials enter into a mass which, as we have seen, is in a way protected from erosion, a small annual contribution may not be unimportant. At present my inquiries concerning the distributions of pumice along the eastern coast of the United States are in a way checked by the need of carefully discriminating between the pumiceous material thrown out from volcanic vents and the similar materials contributed from the boiler furnaces of steamships; the discrimination is possible, but it cannot in all cases be readily effected.

## Dune-sands.

### *OBJECT OF THEIR INVESTIGATION.*

The origin of dune-sands has been well determined, as has also the general principles of their movement; there are, however, many details

of their natural history which, so far as I know, have not been made the subject of inquiry. Some of these I now propose to consider.

### *RESISTANCE TO PERCOLATION OF WATER.*

Those who may have watched the movement of dunes may have had an opportunity of noting that they are often found with their surfaces in the state of dry sand in the course of a few hours after a heavy rain. Observing this fact and knowing how readily water is drawn by capillarity through the materials of which they are composed, I watched the effect of heavy showers on these wind-built hills. To my surprise I found that after a summer shower giving a rainfall of an inch the dune-materials would often not be wet for more than three-fourths of an inch beneath the surface; below that line the sand remains quite dry, wet sand not being found until the section is carried some feet down into the mass.

The explanation of this phenomenon appears to be as follows: When rain falls on dry sand the water finds difficulty in overcoming the repulsion which the dry material offers, and so works but slowly downward; at the same time the interstices of the outer layer permits it to flow down the slopes, keeping near the surface until it reaches the bottom of some depression such as abound on the surfaces of dunes. Here the hydrostatic pressure becomes sufficient to drive the fluid downward. Only in the winter, when the water in the upper part of the dune-sands has been from time to time frozen, do we ordinarily find the mass wet to the depth of a foot or more.

### *MIGRATION.*

*Little affected by Rain.*—In consequence of this peculiarity of dune-sands which retards their deep wetting in ordinary seasons they are retained in marching order. In a few hours after a rain the thin, water-soaked layer, not having water supplied to it from below, may become perfectly dry, so that a strong wind may excavate and bear away large quantities of the material. I am inclined to believe that the ready movements of these sands are in the main to be attributed to these conditions.

*Retarded by Decay of the Material.*—An examination of the dunes of the Atlantic coast has shown that the detritus of which they are composed is generally in process of division and decay. This is indicated by the fact that the materials, if taken from a site where they have evidently remained for years in repose, show the existence of much fine dust, while the recent accumulations and the beach-sands from which they are derived

may exhibit little or none of it. Watching the movement of dune-sands we note that if the marching of the mass be considerable the amount of fine dust blown to a distance by the wind is very noticeable. In fact the indefinite advance of dunes from the shores is to a great extent hindered by this process, by which a large part of their masses is converted into dust which blows far away.

*Prevented by Vegetation.*—The process of decomposition, which is indicated in a large manner by the amount of the dust developed in dune-materials serves in another way to bring these masses into stable conditions. As the decay advances, the mass becomes more and more fitted to sustain plant life, particularly the grasses that have become specially adapted to the environment which these sands afford; of these the common beach-grass is a familiar type. This plant has the habit of sending certain of its main roots to a great depth, where they are tolerably sure of a water-supply; its horizontal shoots are forced laterally at a considerable depth beneath the surface, and are thus in a measure secured against risk of exposure by the movement of the sand, while the leaves by their hard nature and their order of growth are well fitted to resist the cutting action of the blown sand and to bring it to rest in their interspaces. In fact this plant of all the dune-bearing species is the most effective in defending the accumulations from the further action of the wind.

*Limited as to Distance.*—The decomposition of dune-materials is evidently favored by the considerable amount of organic matter which is derived with the sand from the beaches; it is also rapidly promoted by the vegetation which begins to feed in the lean soil, so that the distance inland to which a dune can in ordinary climatal conditions be able to journey is never very great.

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# GABBROS ON THE WESTERN SHORE OF LAKE CHAMPLAIN

BY J. F. KEMP

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CONTENTS



## INTRODUCTION.

The present contribution deals with certain igneous rocks in the townships of Ticonderoga, Crown Point, Moriah, Westport, Essex, Willsborough and Chesterfield, which lie along the western shore of lake Champlain, in Essex county, New York. In them the most important phases of the great igneous body that forms the bulk of the Adirondacks are illustrated, and in many particulars petrographic details are adduced which have not been previously noted from this region. The field work in Moriah and Westport was done with the support and under the direction of Dr F. J. H. Merrill, director of the New York State Museum, and in the other towns, except Chesterfield, with the aid of the trustees of Columbia College, while in Chesterfield and a number of interior townships not mentioned here the writer has had the support and direction of Professor James Hall, state geologist. These results are published with the approval of all concerned.* For five or six years past the writer has been making annual trips into the Adirondacks by way of reconnaissance, and the conclusions are checked, therefore, by a wider

*Geologic maps and sections of these and the remaining townships of the mountains have been or are to be drawn and descriptions written. Those on Moriah and Westport will be submitted to Dr F. J. H. Merrill, those on the others, so far as completed, to Professor James Hall. To each of these gentlemen for permission to use the materials employed in this paper the writer expresses his grateful acknowledgments.

field of observation than the immediate text would indicate. The work will be continued with annual increments of mapped territory. For clearness a brief preliminary sketch of the geology of the Adirondacks is given.

### Review of the Geology of the Adirondacks.

The best known part of this region lies in Clinton, Essex and Warren counties on the east, although even this has been but little explored since the time of Ebenezer Emmons. Of the great stretches of the "North Woods," in Hamilton, Herkimer, Lewis, Saint Lawrence and Franklin counties, much less has been recorded. In the west Professor C. H. Smyth, Jr., of Hamilton College, is working under Professor Hall, and in Clinton and Franklin counties Professor H. P. Cushing, of Adelbert College, as assistant to the writer—likewise under Professor Hall. There is evidence going to show that we have (A) a series of quartz-orthoclase (mostly microperthitic) gneisses, which may contain also hornblende or biotite or augite, and at times much plagioclase; (B) a series of crystalline limestones, often shading into ophicalcites on the east and closely involved with black, hornblendic and pyroxenic schists and gneisses; and (C) a great series of intruded, plutonic rocks of the gabbro family (anorthosites, gabbro proper, olivine gabbros, and norites) which penetrate both the others and are doubtless of later date. The last named series has suffered (as beyond question the others have also) such excessive metamorphism as to be at times strongly gneissoid, and thus to afford, on account of their undoubted intimate association as intruded sheets in the gneisses of A, some extremely puzzling facies. The augitic gneisses of series A are also troublesome as regards their relations, and varieties arise about which there might be justifiable differences of opinion in the present condition of our knowledge, but in their typical outcrops all of these are easily identified and, as a broad division, the classification will probably hold. After series C come the Paleozoic sediments, in practically unaltered condition and representing the Potsdam of the Upper Cambrian, and the Calciferous, Chazy, Trenton, and Utica of the Lower Silurian, all in fine exposures in the Champlain valley.* A great series of feldspar-porphyry and basaltic dikes penetrate

* The close parallel which the above affords with the generally accepted classification of Canada—the Ottawa Gneiss, the Grenville Series, and the Norian—will be at once apparent, but the parallel is not complete or at least not demonstrated in all respects, for our magnetites apparently lie in the lowest of all, while in Canada they are in the Grenville. C. E. Hall, in 1879, proposed for the eastern Adirondacks: I. Lower Laurentian Magnetic Iron Ore Series; II. Laurentian Sulphur Ore Series; III. Crystalline Limestones; IV. Labrador Series or Upper Laurentian with Titaniferous Ores. The relations of II and III are said to be uncertain; but later, in a note the limestone of III is said to be later than IV (32nd Annual Report of the N. Y. State Cabinet, 1879, p. 133). A full review of the literature bearing on the region has been given by the writer (J. F. K.) in the Trans. of the N. Y. Academy, vol. xii, 1892, p. 19, and another by Professor C. R. Van Hise in Bulletin 86, U. S. Geol. Survey, p. 386.

all those mentioned from the oldest to and including the Utica. They are not of stratigraphic moment, although of interesting petrographic characters.*

The great metamorphism of the region occurred before the deposition of the Potsdam, and beyond question in pre-Cambrian times great geologic forces of this nature operated; but all the Paleozoic sediments have suffered faulting and, as Brainerd and Seely have shown by careful work in several districts, especially in Vermont, this is quite extended. The same is generally true of the New York shore, although in less degree. As the Green mountain axis is left behind, these post-Ordovician upheavals and overthrusts are less marked.

## Distribution of the Gabbros.

On the south the gabbroitic rocks are found in the western part of Ticonderoga township as basic members, but unless some doubtful gneisses represent them, they are not in large amount. In northwestern Crown Point township and southwestern Moriah a great ridge offsets to the eastward from the interior mountains and forms an enormous mass in Moose mountain, Harris mountain and others. Anorthosites are chiefly present, with some basic developments, around bodies of titaniferous magnetite on Moose mountain. In Moriah there are various outliers of basic gabbro, but most interesting of all is the exposure along the Delaware and Hudson railway track for three miles above Port Henry. The cuts show dark green walls of this igneous rock, with interesting contacts against crystalline limestone. They afford both normal and olivine gabbro and most interesting passages into gneissoid facies and developments of reaction rims around the basic minerals. All the northern portion of Westport is formed of the gabbroitic rocks, mostly anorthosites, and in the ridge of Split Rock mountain they extend for some miles along the lake shore. Western Essex, including Boquet mountain, consists entirely of the same rock, and Trembleau mountain, running through Chesterfield township, merely repeats Split Rock.

## Facies and mineralogic Composition of the Anorthosites.

In these exposures we find chiefly coarsely crystalline, at times gneissoid facies which contain much more labradorite feldspar than any other mineral. Such are here called anorthosites, following the precedent of Dr F. D. Adams,† and by the term, which in these regions is a practi-

*See Bulletin 107, U. S. Geol. Survey.

†F. D. Adams: Über das Norian oder Ober-Laurentian von Canada. Neues Jahrbuch, Beil. Band viii, p. 423.

cally indispensable one, is meant the abnormally feldspar-rich members of the gabbro family. The anorthosites are in the extreme cases quite pure masses of labradorite, but these have seldom escaped dynamic crushings and now present nuclei of larger fragments surrounded by cataclastic rims. The feldspar at times contains copious inclusions of dusty particles which are opaque and apparently oxide of iron. In some cases pyroxene crystals of minute size have been recognized. All these micro-crystals are regarded as original inclusions taken up as the feldspar crystallized, and the same view is held by Adams * in what seem to be similar cases in the Morin district.

Where the crushing effects have been very strongly developed the rock becomes a white, marble-like variety, usually much altered. The secondary product is white, gives aggregate polarization when light can penetrate it, and surrounds fresh fragments. It is doubtless saussuritic in nature, but, save in exceptionally thin slides, it is practically opaque.

The commonest mineral after the labradorite is a green, monoclinic augite, although this is often scarcely more abundant than a brown hornblende, which is very widespread. In the more basic varieties forming the true gabbros the former often has the extra cleavages of diallage; in other respects it hardly merits more extended description. The hornblende is frequently in close association with the pyroxene, but there seems no reason to think that the former is necessarily of secondary origin. The pleochroism is brown along *c* and *b*, yellow on *a*. Hypersthene is not uncommon, but it is far less abundant than either of the other bisilicates, while biotite, in the area described, is practically limited to the basic gabbros. Deep pink garnets are well-nigh universal, and often associated in the most intimate way with the pyroxene. The same cracks pierce both minerals, and, though the line of demarcation is sharp, the relation makes the observer suspect that the garnet has resulted from preëxisting pyroxene. In the anorthosites proper the reaction rims, cited later as occurring in the basic gabbros, do not appear. Magnetite of titaniferous character is known, but is not abundant in the richly feldspathic rocks.

These anorthosites, while present to a considerable degree in the shore townships, are best developed back in the mountains, and for that reason they are passed with brief mention here. Besides, they are much better known than the true and the olivine gabbros, which are next taken up, and to which this paper is specially devoted. The chemistry of the anorthosites and their component minerals has already been admirably and thoroughly treated by Dr Leeds,† and to his paper Dr Julien has

* Op. cit., pp. 435-438.

† A. R. Leeds: Notes upon the Lithology of the Adirondacks. Thirtieth An. Rep. New York State Museum, 1876.

added some brief notes on the microscopic characters. Dr Leeds also describes the macroscopic characters.

## Occurrence and Petrography of the basic Gabbros.

The more basic gabbros constitute the smaller outlying intrusions and minor portions of the main ridges, which consist chiefly of anorthosite. The best exposure of all is on the lake shore just north of Port Henry. Two great intrusions have come up through the white limestone: one a quarter of a mile above the old Bay State furnaces and one under the Cheever ore bed. Others are met in Moose mountain, in the northwest corner of Crown Point township, where they contain titaniferous magnetites, which have been opened up by prospect holes; still others in fine exposure on a hill (locally called Ledge hill) about three miles due west of Westport village, where they also contain notable titaniferous ore beds; and again as the wall-rock of the old and quite large Split Rock mine, four or five miles north of Westport and fronting the lake. A number of smaller outcrops could also be added, but the above are the best.

These gabbros are rather dark basic rocks, with an ever present tendency on the part of the plagioclase in specimens, not too metamorphosed, to develop a coarse ophitic structure. The broad rods of the feldspar are quite conspicuous, while between them are the dark silicates. The plagioclase is oftenest greenish in the hand specimens from the innumerable inclusions which range themselves toward the center of the twin lamellæ, as shown in figure 2. They render the feldspar practically opaque. They do not appear to be alteration products, but with high magnifying powers are colorless or faint green and rounded. They extinguish with the feldspar, by whose optical behavior they appear overcome. They can only be studied where somewhat dispersed toward the edges of crystals. The feldspar is apparently labradorite. Extinctions in the fresh, clear rims of crystals are prevailingly 5°–7°. Where noted at 20°–25° the emergence of a positive optic axis could be detected. The abundance of inclusions neutralizes any specific gravity determinations. In addition to the faint green inclusions one sees minute crystals of hornblende, and probably also of pyroxene, ranged in regular ranks, and reproducing familiar phenomena. Dark, dusty dots have been noticed by many writers on gabbros and are set forth at length in petrographic text-books. In this connection, those described by G. H. Williams from the Baltimore* gabbros and the norites of the Cortland† series, near Peekskill, may be mentioned, and also those described by Adams from the Morin‡

* G. H. Williams: Bulletin 28, U. S. Geol. Survey, 1886, p. 21.

† Idem.: Am. Jour. Science, February, 1887, p. 141.

‡ F. D. Adams: Neues Jahrbuch, Beil. Band viii, 1893, p. 435.

district of Quebec, and by Lawson from lake Superior;* but in these instances from lake Champlain the dots are nearly or quite colorless and only their enormous numbers, coupled with their refractive properties, lead to opacity. They are not accompanied by rods or other larger or more definite forms, although they themselves are ranged in ranks parallel with the brachy-pinacoid. Figure 36, given by Lacroix† on page 232 of his valuable paper on "Gneiss à Pyroxène et des Roches à Wernérite," is very similar in its general appearance, and the inclusions are said to be of a faint green. The writer is inclined to regard them, as does Lacroix, as fine pyroxenic dust (they are less than 0.01 mm. in diameter) and hence as inclusions and not alteration products.

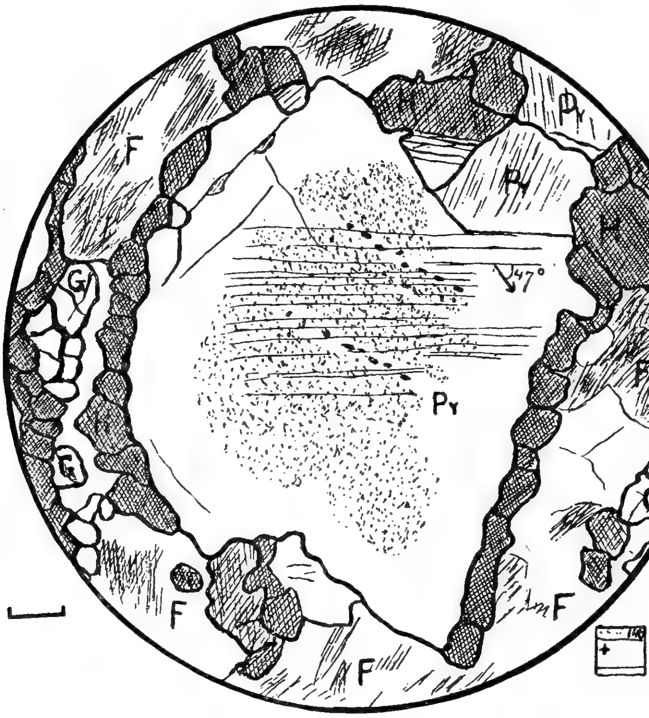



FIGURE 1.—*Thin Section (number 146) of Gabbro.*

Showing reaction rim of brown hornblende (H) between green augite (Py) and decomposed labradorite (F). Specimen obtained near Port Henry, New York.

The other larger minerals are light green monoclinic pyroxene, hypersthene, grains of titaniferous magnetite, and occasionally, but not invariably, irregular crystals of olivine. Almost always around each of these are the most beautifully developed zones, which include, in one and another, brown hornblende, hypersthene, garnet, brown biotite and quartz. The simplest case is shown in figure 1. Around a crystal of pyroxene (Py) a zone of brown hornblende (H) in small individuals has gathered,

* A. C. Lawson: Anorthosites of the Minn. Coast of Lake Superior, Bull. 8, Minn. Geol. Survey, 1893, p. 8.

† A. Lacroix: Bull. de la Soc. Min. de France, vol. xii, 1889, p. 83; see especially p. 228.

preventing at most points the former from coming in contact with the feldspar which is decomposed.* A few small garnets, marked G, appear. More complex than this is the case illustrated in figure 2. Around a crystal of magnetite, undoubtedly titaniferous, have gathered first a rim of brown hornblende, next a zone of pink garnet, and then the feldspar, with its clear rims and clouded interior; but between the garnet and a hypersthene crystal that is marked Hy, there is a further zone of clear irregular bits of quartz. This series is oftentimes increased by the presence of brown biotite next the grain of ore. A most peculiar change appears in figure 3. The interior grain of magnetite is surrounded as

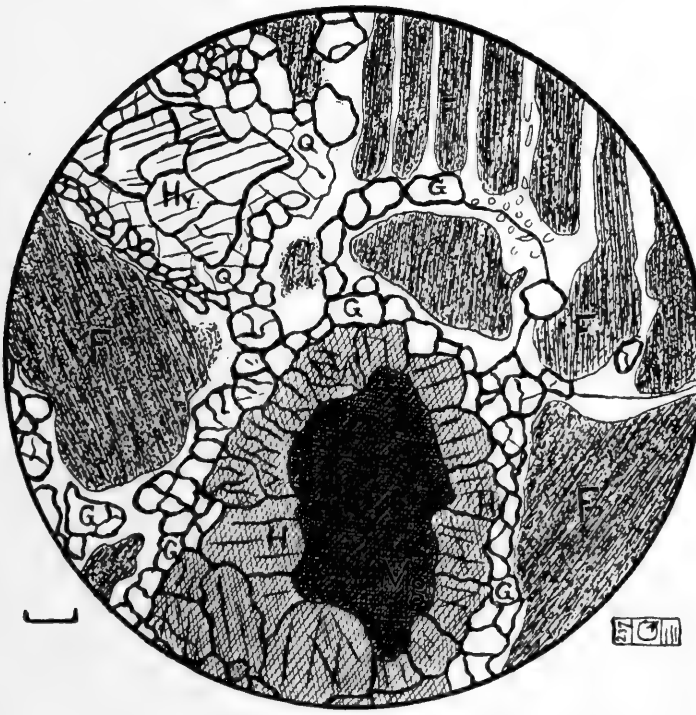



FIGURE 2.—*Thin Section (number 237) of Gabbro.*

Showing reaction rims of successive zones of brown hornblende (H), garnet (G), quartz (Q) around titaniferous magnetite (Mg) or hypersthene (Hy) and between them and labradorite (F). The outer portions of the labradorite are clear because of the absence of inclusions. The specimen was obtained from the hanging wall of Split Rock mine, Westport, New York.

usual by brown hornblende; then follows a clear streak of quartz and next the garnet; the last named is not, however, in irregular grains as before, but has worked into the labradorite, replacing its alternate lamellæ. This has been noticed on several slides, and gives a very peculiar effect. At times only a nest of brown hornblende fragments remains as the nucleus, the core mineral, if such there were, having been all absorbed. An additional mineral sometimes appears next the magnetite and is brown

*Compare Lacroix: Op. cit., p. 245, figure 40.

biotite, the succession outside of it then being as above. Zones or "crowns" or "aureoles," similar in all respects to these except as regards quartz, have been noted by Lacroix in the reference above given and are pictured in the figure there cited. The closeness of the parallel will appear at once to any one who will compare it with figure 2 of this paper, but the replacement of alternate lamellæ of feldspar seems not to have been previously noted. These zones are regarded by the writer as secondary, at least in large part. The garnet certainly is, as shown by its relation to the feldspar. The quartz is doubtless residual silica from the excess left in the alteration to garnet of a more acidic mineral—the labradorite. Of the brown hornblende and biotite one can speak with less

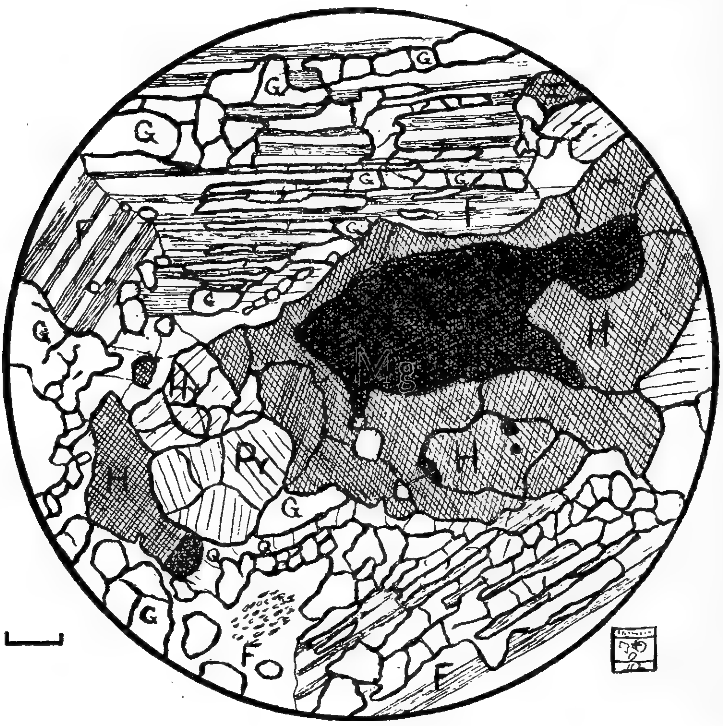



FIGURE 3.—*Thin Section (number* 112) *of Gabbro.*

Showing reaction rims of brown hornblende (H), quartz (Q), and garnet (G) between magnetite (Mg) and labradorite (F). The garnet replaces alternate lamellæ of the labradorite. Specimen obtained from Westport, New York.

positiveness. The nests of the former without a core of magnetite lend weight to the view that they are secondary. Biotite, forming border scales on magnetite is a very common phenomenon in many rocks. Dr Wadsworth* has figured it as secondary in a Minnesota gabbro, and thinks it due to the reaction between magnetite and feldspar. The writer has been previously inclined to regard it as original.†

* M. E. Wadsworth: Minn. Geol. Surv. Bull. 2, 1887, plate vi, fig. 1.

† J. F. Kemp and V. F. Marsters: Trap Dikes in the Lake Champlain Valley, etc. Trans. N. Y. Acad. Science, vol. xi, 1891, p. 19.

The commonest reaction rims or zones of minerals elsewhere noted have been around olivine and apparently due to its proximity to feldspar. In this case we usually see next the olivine a rim of hypersthene granules, outside of which is actinolite in radiating fibers, often with small spinels entangled, and then the plagioclase. Various modifications of this succession have also been recorded, a brief review of which is given below.* In the lake Champlain gabbros the following zones were noted around olivine: Next the olivine is a zone of granular hypersthene, next quartz, next garnet and then feldspar (slide 121), or we may have olivine, hypersthene, brown hornblende, garnet, feldspar (slide 146). There may even be nests of hypersthene bits, with garnet rims, the olivine having apparently been exhausted. In the same specimen of rock (slide 146) the slide shows also the ramifying branches and rods of pyroxene such as were figured by W. S. Bayley † and regarded as original intergrowths. They occur in great numbers in some of the writer's slides, almost forming streams outward from the olivine. In the outcrop north of Port Henry, along the lake shore, most interesting passages of the ophitic gabbro into bands of thinly foliated, gneissoid structure can be traced. This has doubtless been induced by pressure, and the gneissoid character has been caused by the stretching of the dark silicates and of the feldspar into elongated, parallel lenses. In such specimens brown hornblende becomes especially prominent and replaces quite entirely the pyroxene. It would appear to be secondary. Evidence of dynamic effects is everywhere present in the slides.

*A. Olivine surrounded by successive zones of tremolite and actinolite. Törnebohm: in Swedish hyperite. Neues Jahrbuch., 1877, p. 383. Lacroix: in gabbro of Pallet, France. Bull. Soc. Min. Fr., vol. xii, 1889, p. 245.

B. Olivine with successive zones of biotite and talc. Julien: Geol. of Wis., vol. iii, 1880, p. 235.

C. Olivine with successive zones of anthophyllite and actinolite. Becke: in Austria and at Rosswein, Saxony. Tscher. Mitth., vol. iv, 1882, pp. 331, 450. Teall: at the Lizard, in England. Min. Magazine, October, 1888, p. 116.

D. Olivine with successive zones of hypersthene and actinolite. F. D. Adams: from the Saguenay river, Canada. Am. Naturalist, November, 1885, p. 1087. T. G. Bonney: from Aberdeenshire. Geol. Magazine, October, 1885, p. 439. J. H. Hatch: from Madagascar. Quar. Jour. Geol. Soc., May, 1889, p. 343. J. W. Judd: locality not stated. Jour. Chem. Soc. London, vol. lvii, 1890, p. 423. W. D. Matthew. gabbro near Saint John, New Brunswick. Trans. N. Y. Acad. Sci., April, 1894. Probably the cases cited by G. H. Williams of olivine, colorless pyroxene and actinolite belong here. Baltimore gabbros, Bull. 28, U. S. Geol. Survey, 1886, p. 52; Peekskill, N. Y., Am. Jour. Sci., January, 1886, p. 35.

E. Olivine with successive zones of hypersthene and garnet. Kemp, this contribution, 1893.

F. Hypersthene with successive zones of actinolite and hornblende. G. H. Williams: Baltimore gabbros. Bull. 28, U. S. Geol. Survey, 1886, p. 42.

G. Titaniferous magnetite surrounded by successive zones of biotite, brown hornblende, garnet. Lacroix: at Odegarden, Norway. Bull. Soc. Min. Fr., vol. xii, 1889, p. 232. Kemp, this contribution, 1893; also with zone of quartz.

Other zones like the "kelyphite" around garnet are not mentioned here, as they have no direct connection with this paper.

† W. S. Bayley: Fibrous Intergrowths of Augite and Plagioclase in a Minnesota Gabbro. Am. Jour. Sci., June, 1892, p. 515.

## Titaniferous Magnetite Ore Bodies.

Another interesting feature of the gabbro exposures is found in the contained bodies of titaniferous magnetite. The one on Split Rock mountain is shown by the excavations to be large. The breast is ten feet or more across, and has been taken out on two levels for 100 feet. The wall rock right up to the ore on each side is a dark, basic gabbro, with the reaction rims well developed. The ore itself is simply an extremely basic phase of the gabbro magma. The following analyses are quoted by Mr A. J. Rossi.*

| | I. | II. | III. |
|---|---|---|---|
| Fe | 44.77 | 32.59 | 40.42 |
| $TiO_2$ | 13.15 | 14.70 | 16.37 |
| $Fe_2O_3$ | 61.8 | 45.0 | 55.8 |

The metallic iron has been calculated as $Fe_2O_3$ in the third line, but it only serves to show that the ore is very low grade, and that there remain 25 to 40 per cent unaccounted for. Beyond question this remainder consists of $Al_2O_3$, MgO and CaO, the familiar bases of pyroxene, hornblende and labradorite. Mr Rossi remarks on the general high percentage of $Al_2O_3$ in these titaniferous ores from neighboring prospects. They also run, as a general rule, low in sulphur and phosphorus. The same geologic surroundings accompany the other titaniferous ores referred to in a previous page, but at times black hornblende (as on Ledge hill, Westport) is very abundant next the ore, for the wall shows little else than coarsely crystalline masses of this mineral, which pass into the ore itself. In all of these mines there is no evidence of a fissure or of vein formation, no slips or salbands, nor at Split Rock, at least, does the wall rock lack a purely massive habit. The origin of certain iron-ore bodies as excessively basic developments of an igneous magma has been favored by not a few of the late writers. The interesting ore at Cumberland Hill, Rhode Island, described years ago by Dr Wadsworth † as an intrusive peridotite; the ore bodies in Minnesota gabbros, cited by N. H. Winchell; ‡ others in nepheline rocks in Brazil, described by O. A. Derby, §

* A. J. Rossi: Titaniferous Ores in the Blast Furnace. Trans. Am. Inst. Min. Eng., February, 1893. Many other analyses of titaniferous ores from other regions are given by Mr Rossi.

† M. E. Wadsworth: Bull. Mus. Comp. Zoöl., vol. vii, 1881, p. 183.

‡ N. H. Winchell: Tenth An. Rep. Minn. Geol. Survey, 1882, pp. 80–83.

§ O. A. Derby: Am. Jour. Sci., April, 1891, p. 311. Mr Derby informs the writer that this ore contains up to 20 per cent $TiO_2$. Even with high $TiO_2$ percentages it may be a natural lodestone, a fact not to be overlooked in discussions of magnetic separations of titaniferous ores.

and many examples of the same in Sweden, which have been long known, but lately brought again to mind by J. H. L. Vogt;* all these are illustrations of the same process, and doubtless many nickeliferous pyrrhotites will fall in the same category. Whether any non-titaniferous iron ores will be found which admit of this explanation remains to be seen.

## Contacts of Gabbro and Limestone.

The gabbro of the exposure north of Port Henry has been intruded beneath and in part through crystalline limestone, into which it appears to have also sent out some apophyses in the shape of dikes. Superb contacts are shown in the railway cuts along the lake shore. The limestone has been much disturbed by dynamic movements since the intrusion and exhibits strongly the characteristic plasticity of this rock under such stresses. Next or near the gabbro it is coarsely crystalline and abundantly charged with bunches, often of great size, of various silicates peculiar to such situations. Dynamic movements have bent these into many fantastic curves and shapes, often suggesting animals of various sorts.† These bunches of silicates consist of quartz, plagioclase, diopside, pale brown hornblende, scapolite, biotite or phlogopite, pyrrhotite, tourmaline, titanite ‡ and some other less common minerals. Rose quartz is at times abundantly associated. These minerals often show the effects of the dynamic movements mentioned above, and the writer has already cited (in the reference given below) the case of a tourmaline one and one half inches long which was bent around through an angle of 70°. The minerals are in instances well bounded, especially when calcite is particularly rich in the mixture, but in most cases they are merely allotriomorphic aggregates, whose characters are best revealed by the thin section. In the abandoned Pease quarry in the northerly outskirts of Port Henry great horses of these silicates appear, and at the top of the ledge formed by the quarry face is a large dike, doubtless an offshoot of the underlying gabbro which one meets at the lake shore below. It is itself somewhat metamorphosed and shows allotriomorphic brown hornblende, malacolite and plagioclase in all respects like those described by the writer from the neighborhood of West Point on the Hudson.§ Contact masses of silicates similar to those above described are characteristic of not a few exposures of white crystalline limestone in this eastern part of the United States, and always near them the igne-

*J. H. L. Vogt: Zeitschrift für Praktische Geologie, vol i, 1893, pp. 4, 25, 257.

†The best illustrations are on the north side of Split Rock, in the town of Essex.

‡J. F. Kemp: Notes on the Minerals occurring near Port Henry, N. Y. Am Jour Sci., July, 1890, p. 62.

§J. F. Kemp: Dikes of the Hudson River Highlands. Am. Naturalist, August, 1888, p. 691.

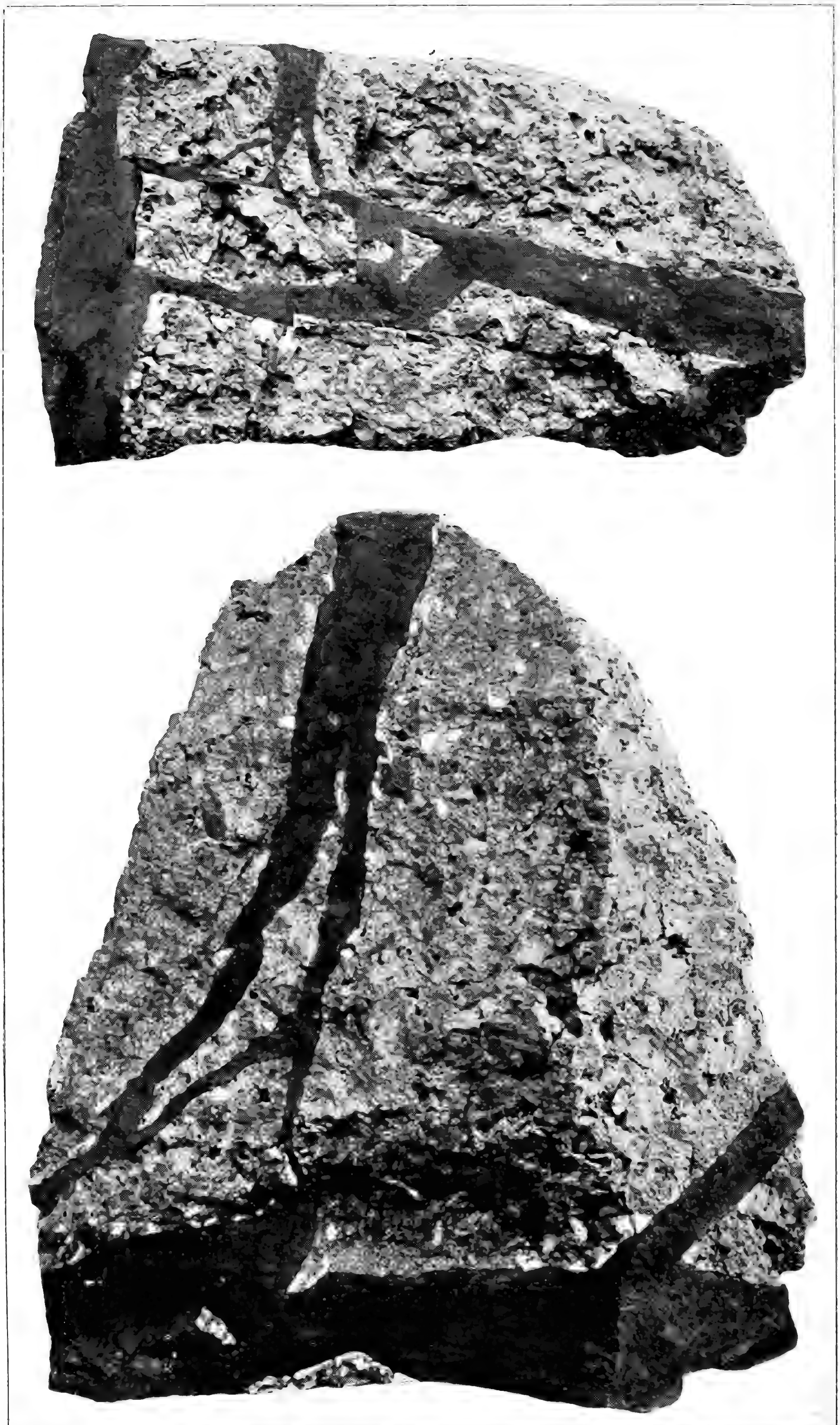
ous intrusions are found.* Scapolite is especially characteristic of such, and invariably with it are hornblende, pyroxene and titanite.

## Conclusions.

The exposures treated in the above pages illustrate again the variability of great masses of gabbroitic rocks and the rapid changes from place to place which they so frequently show, both in mineralogy and structure. This has been already noted by G. H. Williams, F. D. Adams and others. We need not be surprised to find examples extending from quite pure feldspathic aggregates to basic gabbros, and even, as in the Baltimore and Peekskill exposures, to peridotites and pyroxenites, but at the same time the close genetic relations of such rocks cannot be too strongly emphasized by petrologists. The wide distribution of the reaction rims, corrosion zones, crowns, aureoles, et cetera, call them as we may, is also worthy of remark, as so many gabbros show them in various parts of the world. The same is true of the bodies of iron ore which mark the extreme phase of basic development, although in relatively limited amount and of very local character. In many places the contact effects of these intrusions on limestones are so similar that one is inclined to suspect the near presence of igneous rocks wherever these contact minerals, and especially scapolite, are reported in limestone.

*Compare J. F. Kemp: On Van Artsdalen's Quarry, Bucks County, Pennsylvania. Trans. N. Y. Acad. Sci., vol. xii, 1892, p. 19. Kemp and Hollick: On the Granite of Mount Adam and Mount Eve, Orange County, New York, and its Contact Phenomena. Annals of the N. Y. Acad. Sci., vol. viii, January, 1894.

Not a few similar cases are cited by Lacroix in the paper on "Gneiss à pyroxène et des roches à wernérite," to which frequent reference has been made above.



SANDSTONE DIKES IN GRANITE
ABOUT TWO-FIFTHS NATURAL SIZE.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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# INTRUSIVE SANDSTONE DIKES IN GRANITE*

BY WHITMAN CROSS

*(Read before the Society December 28, 1893)*

CONTENTS



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*Introductory.*—The phenomenon to be described in the following pages is that of the occurrence of sandstone—a rock composed of worn sand grains—as the filling of an extensive system of fissures in granite and under circumstances indicating that the sand was forced into the fissures under great pressure.

*Region of Occurrence.*—The sandstone masses in question occur in the Pikes peak region, in Colorado, and were discovered in the course of a geological survey of the district during the past summer of 1893.† The dikes observed are limited to a belt about ten miles long and one mile wide, with a trend north-northwest to south-southeast, the southern end of which is about five miles north of Pikes peak. This belt lies on the western side of the narrow Manitou park basin of sedimentary rocks, at a distance six to eight miles west from the border of the Great plains, and 1,500 feet above them.

* Printed by permission of the Director of the United States Geological Survey.

† Prior to entering upon the field-work Professor G. H. Stone, of Colorado Springs, called the writer's attention to the occurrence of isolated sandstone bodies in the Pikes peak granite area, the origin of which was not known to him. Some of the masses referred to by Professor Stone were found to be dikes, while others were of entirely different character. In the field study of the dikes Mr E. B. Mathews, Fellow in Johns Hopkins University, took part, as geological assistant.

*Characteristics and Mode of Occurrence.*—The dikes have a general trend parallel to the belt in which they occur. They stand vertical or have a steep dip to the northeast, and often appear as a complex of nearly parallel fissures with many branches and connecting arms. In width they vary greatly. The larger number are a few inches or a few feet thick, but many of the smaller branches thin out to a mere film. On the other hand several dikes are many yards wide, and two form prominent ridges with a width of from two to three hundred yards each.

The length of the dikes cannot be accurately determined, for the surrounding granite is so much disintegrated by weathering that its gravel covers and conceals the dikes wherever they are broken down. The largest ones, however, may be followed for nearly a mile, and they are doubtless directly connected with some of the smaller ones whose outcrops are interrupted by the granite gravel. All evidence tends to show that the dike fissures belong to a single system and that they are connected at points not now exposed. Certain bands of small dikes are visibly connected by so many cross-fissures that the granite is locally divided into wedges or angular blocks. The figures of the accompanying plate, representing two faces of the same specimen, illustrate the character of the fissures and their complicated branching, such as may frequently be observed between the larger dikes of a complex.

The larger dikes form ridges with narrow crests rising abruptly three or four hundred feet above the parallel gulches. The hard and much jointed dike-rock causes very rugged forms contrasting markedly with the gently sloping hills of granite about them. Dikes a few feet wide often stand out as walls above the gravel surface.

The smaller dikes have walls which are apparently parallel planes and the contacts are very sharply defined. The larger ones have a flat lenticular shape in horizontal section. In all formal relationships to the enclosing rock these bodies are as typical dikes as any of igneous origin.

As the best exposures of these bodies are easily accessible from either the Woodland Park or the Green Mountain Falls station on the Colorado Midland railroad, some further details of their occurrence will be given, for the benefit of those who may have opportunity to visit this district. At a point one and one-half miles above Green Mountain Falls the main western branch of Fountain creek issues through a narrow gulch in granite hills into the southern end of the long depression occupied by the sedimentary rocks of Silurian and of Carboniferous (?) age, which extend from this point northward for eighteen miles through Manitou park.* The sandstone dikes are most beautifully shown on

* See Hayden's Atlas of Colorado, sheet xiii.

both banks of this branch of Fountain creek for two miles or more above the forks. On the northeast side is one of the largest dikes, forming a sharp and very jagged ridge more than half a mile long. On the opposite hillside numerous small dikes are exposed, but the most excellent outcrops are about one and one-half miles above the forks of the gulch, where its course is east and west, on the northern side. Here several bands of small dikes are found, some forming wall-like projections, while the ramification is very plain.

Another excellent exposure of dikes has been made by a railroad cut one and one-half miles southwest of Woodland Park, on the west side of a little divide. Here the road turns abruptly to the south around a hill of red quartzite caused by a large dike, whose contacts are not well shown, except in the cutting on the west side, at which place the main contact is exposed, and also a dozen or more small dikes, within fifty feet of the large one. The relationships are very clear at this point.

The largest dike is one and a half miles due west of Woodland Park. It forms a ridge several hundred feet high, of very rugged outline, and its maximum width was estimated at over 300 yards, though the exact contacts were covered by débris at the points visited. This dike extends northward for a mile or more with decreasing thickness and probably divides into several branches. It is not known how far the dikes extend to the northward.

*The Dike-rock.*—The rock of the dikes is a fine and even-grained aggregate of sand grains, variously indurated. In some cases it has the saccharoidal texture seen in many massive sedimentary sandstones, but it is more commonly indurated to a dense, hard quartzite. Except for a local and subordinate banding adjacent and parallel to the walls of a few dikes, the rock, even of the largest dikes, is remarkably massive and uniform in character from wall to wall. A dull red color, of various shades in different dikes and due to flakes of limonite, is characteristic of the masses.

The rock is extremely tough, as a rule, and the breaking down of the dikes is chiefly due to a jointing, which is generally developed parallel or at right angles to the walls, but may be quite irregular. This jointing produces débris of small, sharply angular fragments, which, as talus, conceals the contacts of the larger dikes in most places.

The constitution of the dike-rock is evident to the naked eye in most cases, and a hand-lens shows the character of the densest masses. Microscopical examination simply demonstrates the extraordinary purity of the sand, showing that it consists almost wholly of quartz grains, many of which are well rounded, while few are sharply angular. There is a very

little clear feldspar, either orthoclase, microcline or plagioclase. Many of the quartz grains contain inclusions of apatite and zircon and a few small, round inclusions probably of hornblende, but neither mica, amphibole nor pyroxene has been seen in sand particles. The average size of the quartz grains is less than 1 mm., and in many cases is less than 0.5 mm. A few larger grains are seen in some dikes.

The induration is mainly due to limonite in small flakes, and in less degree to muscovite in minute leaflets wrapped about the grains. Occasionally there appears to be some secondary silica, but a distinct enlargement of the quartz grains is rare. Tourmaline and other corresponding secondary minerals are wholly absent. Minute fluid and gas inclusions are common in the quartz.

The mineral composition of the sand and the size and form of the grains are practically the same in all dikes, large and small. Occasionally angular fragments of the adjoining granite are mingled with the sand, but cases are extremely rare where any difficulty arises in distinguishing this material from the sand of foreign origin.

*Origin of the Dikes.*—As far as the writer is aware, no other occurrence of sandstone dikes in granite has ever been described. As dikes of sandstone they may be compared with the remarkable occurrences in California described by Diller* in the first volume of this Bulletin; but the dikes of this latter occurrence were in shales of a great sedimentary complex of Cretaceous age, and they were parallel to a system of jointing planes in the strata. Moreover, Diller noted that below the horizons occupied by the dikes there occurred sandstone strata of a composition identical with that of the dike-rocks. The very plausible theory presented by Diller was that the fissures represented by the dikes were formed by earthquake shock, and that the sand was injected as quicksand into the fissures under hydrostatic pressure from unconsolidated water-bearing sand layers below. He observed many minor details supporting this theory.

It is clear that the sandstone dikes described above are far more difficult to explain than those of California, in that the known facts do not indicate the source of the sand; yet the physical and mechanical facts do seem to show that the fissures of this dike complex were filled by fine quicksand injected from a source containing a large amount of homogeneous material. On the one hand, it is impossible to suppose that such a system of fissures, large and small, with their many intersections, could remain open to be filled by any slow process, and, on the other, it is equally impossible to believe that the uniformity and purity of the mate-

* J. S. Diller, Sandstone Dikes: Bull. Geol. Soc. of Am., vol. 1, 1889, p. 411.

rial filling fissures, varying from mere films on cleavage planes of orthoclase grains in the granite to dikes several hundred yards in width, could have resulted from infiltration.

It has been stated above that the belt of observed dikes lies adjacent and parallel to the Manitou park basin of sedimentary rocks, the principal element in which is the red sandstones and grits of the Carboniferous (?) or Trias (?). These beds are, however, of much coarser and more heterogeneous character than the dike-rock, and the observations made do not suggest that the proximity is anything more than accidental. It is not known that the dikes are younger than the sediments, for they were nowhere found in contact. The strata of the basin are now seen at the same level with the dikes, but faulting and a synclinal fold have clearly lowered them with reference to the granite on either side. Finally, it is probable that the dikes are not limited to the vicinity of the sedimentary basin. Neither end of the belt containing the dikes was determined, and an observation by Professor G. H. Stone shows plainly that sandstone dikes do occur in the same general strike line and far removed from any sedimentary rocks.

Professor Stone* has published a short note on "The Turkey Creek Mining District, El Paso county, Colorado," which lies to the southeast of Pikes peak, in the granite mountain area and several miles from the border of the plains. The locality is about eighteen miles a little east of south from the southernmost dike observed by the writer. Referring to the principal lode, Professor Stone describes it as follows:

> "It is a narrow strip of pink or reddish rock that outcrops at intervals and has been located for about 12 miles. Its direction is nearly north and south. It is bordered on both sides by granite-gneiss and other Archean rocks. To the unassisted eye this so-called lode often presents the compact appearance of an igneous rock, but examined in thin section under the microscope it is plainly seen to be a fine-grained sandstone. The grains are of quartz. They are nearly all well rounded, and their interstices are filled with an iron-rusty cement. In places the grains are larger, some one-sixteenth of an inch in diameter, and easily recognizable by the eye."

Through the courtesy of Professor Stone the writer has been able to examine a thin section of this "lode" rock, and it is, as would appear from the above description, identical in character with the dike-rocks to the north of Pikes peak. If then the Turkey creek rock belongs to the dike system described in this paper, it is unlikely that the latter has any direct connection with the sedimentary rocks of Manitou park. Further

*Engineering and Mining Journal, September 9, 1893.

detailed study is necessary before a plausible theory as to the origin of these dikes can be advanced.

The coincidence in direction between the dike system and the structural axis of the Front range would indicate that the dike fissures were formed during some period of orographic movement; but as movements parallel to this axis are known to have been repeated at intervals from very remote geologic periods down to the Tertiary or even more recent time, this coincidence is of no value in ascertaining the age of the dikes.

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# CRUSTAL ADJUSTMENT IN THE UPPER MISSISSIPPI VALLEY

BY CHARLES ROLLIN KEYES

(*Presented before the Society December 29, 1893*)

CONTENTS



## INTRODUCTORY.

The effects of orogenic movements so obvious everywhere in all mountainous regions rapidly lose their more salient characteristics as the distance increases from the heart of the system to the more level, plain-like districts above which they rise. In the lowland plains, such as exist in the Mississippi basin, the corrading power of running water is reduced to a minimum, and profound secular decay or heavy glacial accumulations obscure almost completely everything except the most prominent structural features. Indications of low folds or shallow synclines are often visible in this region, but dislocations of strata are rarely found. That the latter are much more frequent than is perhaps generally supposed,

subsequent considerations will show. The phenomena here recorded apply more especially to the western interior coal basin occupied in part by Iowa and Missouri, as in this district most of the observations were made.

## CARBONIFEROUS BASIN OF THE MISSISSIPPI VALLEY.

*Extent.*—The broad undulatory plain which occupies the central portion of the American continent, stretching out from the base of the Appalachians to the foot-hills of the Rocky mountains, makes up the principal portion of what is known as the Continental Interior region. It spreads out in one direction for more than nine hundred miles and in another over twelve hundred. Its superficial contents are upward of one million square miles, or more than one-third of the entire areal mileage of the United States. This vast expanse of country, whose surface is unbroken by mountains and whose borders are untouched by the waters of the sea, has been aptly designated a great basin. The Great Mississippi basin it is called, from the majestic river, the "Father of Waters," which flows centrally through it.

The region may be properly regarded as a wide stretch of lowland sloping gently in all directions from the margins toward the center and southward. The "Great Plains" form the western portion of the region; the rolling prairies of the "Upper Mississippi" the median part; the fertile valley of the Ohio and the Cumberland plateau the eastern section. No marked contrasts of altitude break the surface relief of the Mississippi basin. The lowest point, in the south-central part, is about four hundred feet above tide level; the highest places are on the northern and western margins, where the mean elevation is not far from two thousand feet.

The contrasts of relief to be noted in considering the Interior basin are not those between different parts of the plain itself, but those between the basin as a whole and the region immediately around it. Beyond the boundaries in nearly every direction a mountainous physiognomy is presented. The Appalachians on the east and southeast, the Rocky mountains on the west, the highlands of the Great lakes region northward, all stand out sharply against the country they surround. They all tell of powerful dynamic action which has been at work elevating broad stretches of territory; of continental movements which have operated on a grand scale.

On the whole, erosive agencies have not acted vigorously since the deposits of the Mississippi valley were originally laid down in the old Carboniferous seas. Through most of the long period, from the time when the beds were first raised above the level of the waters of the great

interior sea at the close of the Carboniferous age to the present date, the vast region must have been nearly the same level lowland that it is today; a plain whose surface has remained nearly at baselevel for ages, sometimes rising slightly, sometimes sinking a little, but never oscillating far either one way or the other.

*Structure.*—Great as is the difference between the broad central area of low lying plains and its high serrated borders, there is a diversity of structural features in the geologic details of each of the two districts as distinct and as far removed from one another in character as are the two widely separated types of surface sculpture. On the one hand, throughout the marginal region of the interior basin the elevation of the land has been accompanied by violent disturbances in the strata—folding, crumpling, breaking, grinding the once horizontal beds until now they lie at high angles, with upturned edges everywhere exposed to the swift ravages of nature's destructive agencies. The bold, rugged contours of the mountain surface thus disclose the complicated structure of rocky beds beneath. On the other hand, the lowland plain presents its strata spread out in broad, nearly level sheets much in the same position as when they were first laid down. Although made up almost entirely of sediments dating back in their origin to old Paleozoic times, it is indeed quite remarkable that, formed at a period remote even in geologic units of time, the structural changes should be no greater than they are and that the region should still retain over the greater part of its extent the same simplicity of geologic structure that is found today among the modern depositions of the coastal plains which fringe the great land areas of the globe. The hypsometric changes over the whole region have been, therefore, of the character of continental elevation and depression.

*Geologic Provinces.*—The present boundaries of the Mississippi valley form approximately the limits of an area which in Carboniferous times had a development peculiarly its own and in a great measure unaffected by events transpiring in neighboring districts. The origin and deposition of its strata, the lithologic characters of its beds, and the succession and evolution of its faunas were wholly independent of the surrounding areas. In short, the Carboniferous basin of the Mississippi valley represents, in every sense of the word, what in geology is called a "geologic province."

*Character of Deformations.*—The great economic value of the coal-bearing formation of the Mississippi province has directed particular attention to its geology. Within the limits of the region it may now be said that the Coal Measures have received more careful attention than any other of the geologic formations represented; but at the same time, for

this very reason, the stratigraphic importance of the formation has been greatly overestimated. It has led to the attachment of far too much significance to really trivial characters, which, though they may be quite conspicuous in themselves, are of comparatively small value. Features which in other formations would be entirely overlooked, in connection with coal seams become greatly magnified on account of their bearing upon the expense of mining. Among these factors may be mentioned the various kinds of folds or flexures, faults, slips and "cut-outs."

## Folds.

*Principal Features.*—Though composed of flat lying beds as a rule, the strata of the Continental interior nevertheless present evidences of orographic movements, though they may perhaps in most cases be slight. Probably the most apparent expression of this action is shown in a series of low folds the general trend of which is north and south. The most prominent of these great corrugations are five in number.

In the extreme east of the region there are the most westerly anticlines of the Appalachian system of mountains with its closely appressed folds running southwestward from New England to central Alabama. Next is a broad dome-like elevation which finds expression in the uplift of central Tennessee, the Cincinnati arch and the minor elevations of the older rocks in northern Ohio and western Ontario. The axis of this fold extends from lake Huron southward, with a little inclination to the west. Midway between the two great mountain chains of America is a third slight fold whose anticlinal axis extends approximately along the line of the Mississippi river. It is shown in the rocks of central Arkansas, in the eastern part of the Ozark uplift, in the many exposures of strata older than the Carboniferous in northeastern Missouri and eastern Iowa, in the "Isle of Wisconsin," and in some of the ancient crystallines of the lake Superior region. The outcrops of the older Paleozoic rocks along the Mississippi river cannot be regarded as due entirely to unaided erosion. Apparently the deep gorges of the great river are due partly to the results of the ordinary action of running water; partly to the result of an accelerated erosion on account of the gradual elevation of the principal line of drainage. There is evidence at hand to show that the movement, slight as it may have been, had already begun before the close of the Lower Carboniferous in the present upper Mississippi valley. The fourth fold is perhaps somewhat imperfectly defined at present, but it is indicated by a line of small areas of very ancient rocks trending northwesterly through central Texas and Indian territory, and protruding through much younger strata. The last is a series of deformations

on the extreme west, forming the easternmost range of the Rocky mountains. The trend of the axis is southeastward.

It is a significant fact that the axes of all five of the great folds when prolonged strike approximately the same point in the Gulf of Mexico, a short distance from the mouth of the Mississippi river, a place where a maximum load of sediments from the North American continent is now being deposited; or, in other words, the axes radiate from this point.

Comparatively simple in its general geologic structure, easy of subdivision into tolerably well-defined minor groups according to lithologic features, and abundantly supplied with characteristic fossils in all its beds, the Paleozoic series of the interior basin still possesses stratigraphic phases highly complicated in their nature. It is an arrangement of strata such as might occur along the coast of any continental mass receiving sediments from numerous sources and forming very distinct interlocking beds, each of which rapidly or gradually thins out in all directions and is replaced by others. It is an arrangement which presents great difficulties to a natural geologic classification of the beds that would be applicable to all portions of the district, both on account of the vastness of the province and the multiplicity of conditions under which the depositions were made.

*Minor Corrugations.*—Besides the flexures just mentioned, there are in the region many smaller folds and synclines, which have a trend independent of the larger ones. These are usually grouped into series of more or less limited extent, the different series being independent of one another. Their existence has long been known, yet the extent and amplitude of none have been determined with accuracy. In Iowa a number of low folds have been recognized. Their axes have a northwest-southeast direction in the eastern part and northeast-southwest in the western portion of the state. Several have also been made out in central Iowa. In the neighboring states similar small folds have been noted from time to time.

## FAULTS.

*Alleged Faulting.*—In the early days of geologic exploration in the Mississippi valley, faults, many of considerable extent, were frequently reported at different places. In his canoe voyage up the Des Moines river from its mouth to the Lizard fork, near the present site of Fort Dodge, Owen recorded a number of very marked instances. Worthen, who made the same trip a decade later, also claimed to have recognized some very striking dislocations of the strata. Subsequent investigations have not only failed to substantiate the earlier observations, but have proved con-

clusively that most if not all of the "faults" in question have no existence. A notable instance is the "great fault" at Elk Cliff, in Marion county, which Owen* reported as having a throw of more than 150 feet. Lately careful examination of the locality has shown without the slightest doubt that the abrupt change in lithologic features at this place in the short distance of a few rods is due largely to erosion during Carboniferous times. At Redrock bluff, two miles above Elk Cliff, the old steep-sided channels of erosion are upward of 100 feet in depth. Faults of 50 or 75 feet have been reported from other places in the Iowa coal-field, but in every case investigated no satisfactory evidence has been obtained to substantiate the claims.

Farther south in Missouri, on the Mississippi river above Saint Louis, the Cap-au-Grès "fault" has been estimated to have a development of more than four hundred feet. Others of minor note have also had attention called to them.

*Dislocations in Iowa.*—In all the Iowa coal-field less than half a dozen true faults are known to be clearly defined in surface exposures, for, as in most cases of faulting, the exact line of displacement is commonly more or less completely obscured through the weathering of the strata or by extensive superficial deposits. Ordinarily it would be impossible to recognize these faults, except as fortunate artificial excavations reveal them. The development of the coal-mining industry in the state, however, has been the means of disclosing series of small faults which would otherwise have remained forever unknown. Owing to the important rôle stratigraphic displacements play in the economy of mining, slips of only two or three feet are brought quite prominently into account. The large number and proximity of these small faults have been in some cases rather surprising, and the chief object of the present paper is to call attention to some of the dislocations as presented in the Iowa coal-field.

*Normal Faults.*—All the faults observed are of the normal kind, with a hade varying from a few to sixty or seventy degrees and a throw of from a few inches to several feet. The ruptures and slippings in the workable beds of the Iowa Coal Measures rarely interfere seriously with mining operations as they often do in other regions, yet their geologic import is significant. It has been only through he extensive removal of comparatively thin beds that they have been brought to light. The line of displacement as displayed in a mine entry is usually as sharply defined as if drawn with a pencil, though often theedges of the two parts are sometimes broken. In most cases the planes of sedimentation for a few inches on each side of the fault line are bent more or less sharply upward on the down-throw side and downward on the up-throw side.

*Geol. Survey Wisconsin, Iowa and Minnesota, Philadelphia, 1852, p. 117.

The two surfaces along the line of movement which have been rubbed together are commonly very dense, hard and highly polished, forming what is usually termed "slickensides." The common appearance of these faults as they are encountered in mining is represented in figure 1, which is taken from the Bloomfield shaft near Des Moines. It is typical of quite a large number occurring in this and other mines. Sometimes the slips are quite small (figure 2) and die out in the coal vein itself, as shown in the Thistle mine in Appanoose county. An especially interesting fault has been observed in the American mine in Mahaska county, where the line of movement has been directed through a narrow nodular band or elongated mass of clay ironstone (figure 3). The line of breakage in passing from the softer to the harder layer is

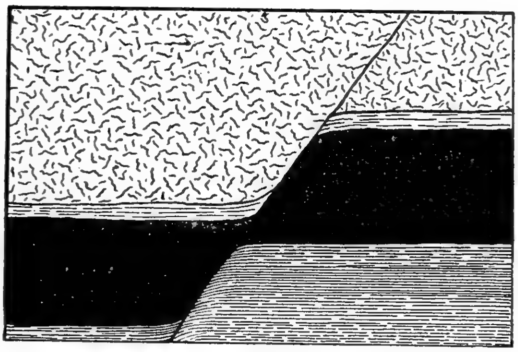

FIGURE 1.—*Fault in Bloomfield Shaft, Des Moines, Iowa.*

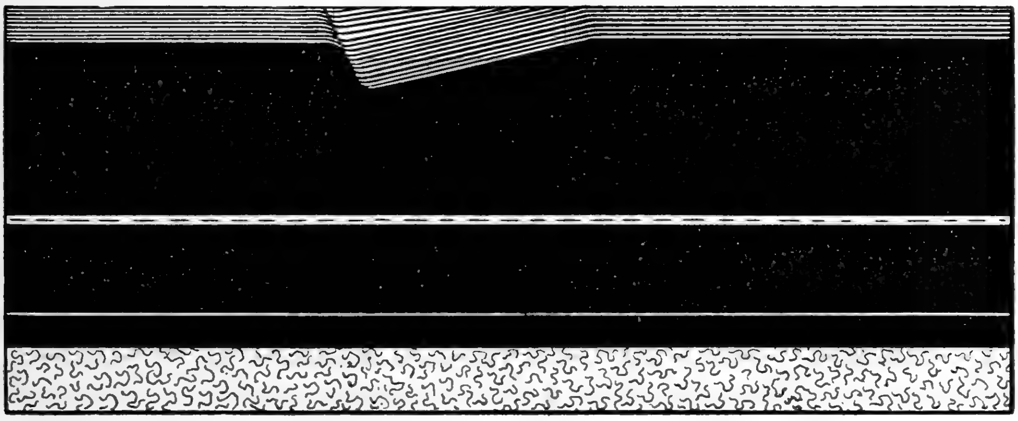

FIGURE 2.—*Deformation in Roof of Thistle Mine, Appanoose County, Iowa.*

changed in direction, being bent toward the normal, while after passing into the coal seam again it assumes its original direction. This phenomenon is essentially the same which has been recognized in slates where hard grit bands are intercalated.

*Step Faults.*—Where the ordinary normal fault is repeated a number of times within a short distance the step fault is formed. Exposures of this kind are well shown in the Davison mine in Jasper county. Figure 4 represents a section through part of one of the entries, although the entire series is not here reproduced. The fall of the displacements is

from six inches to several feet, the inclinations being about forty degrees. Another similar series occurs in the Deep Vein mine in Monroe county. In all cases the faults are practically parallel to one another. In some places the effect of the strain instead of appearing in faults is relieved

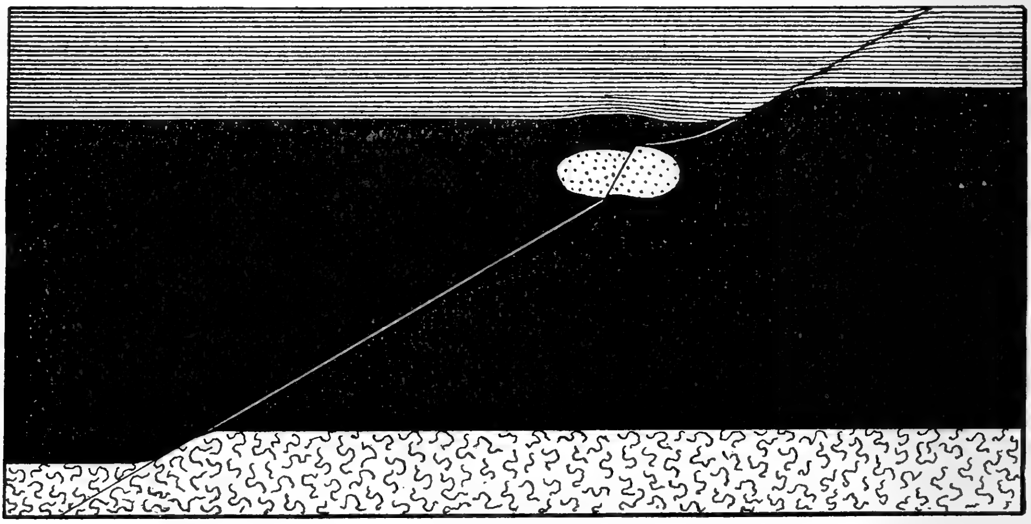

FIGURE 3.—*Fault in American Mine, Mahaska County, Iowa.*

partly by small sharp folds without direct fractures. From an examination of numbers of these small faults and of others of similar character in mountainous regions it would seem that the adjustment of tension in the earth's crust here, as in districts of greater deformation, is accomplished by means of many small slips rather than by a few large ones.

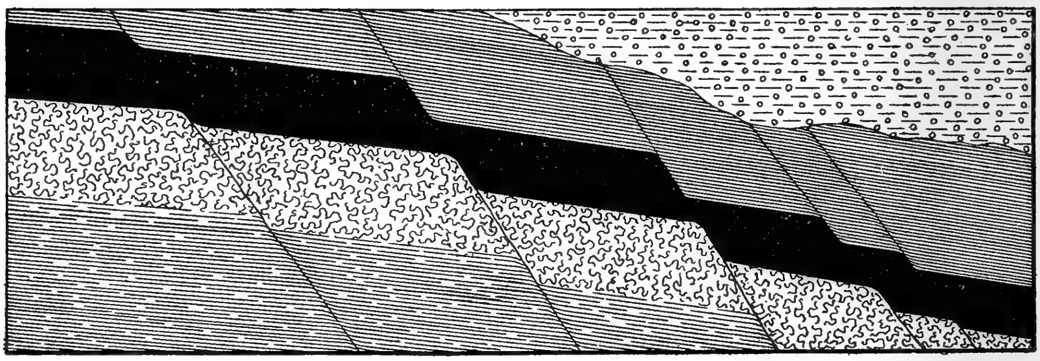

FIGURE 4.—*Step Fault in Davison Mine, Jasper County, Iowa.*

Similar faulting has been worked out in the mountain districts of California, where recently Becker has made some extended and extremely interesting observations in this direction.

*Trough Faults.*—A special case of the ordinary normal fault is when two slips with hades in opposite directions occur close together, allowing

a more or less distinctly wedge-shaped portion to be displaced. These are commonly called trough faults. One observed in the Appanoose shaft in the southern part of the state is represented in figure 5. Here

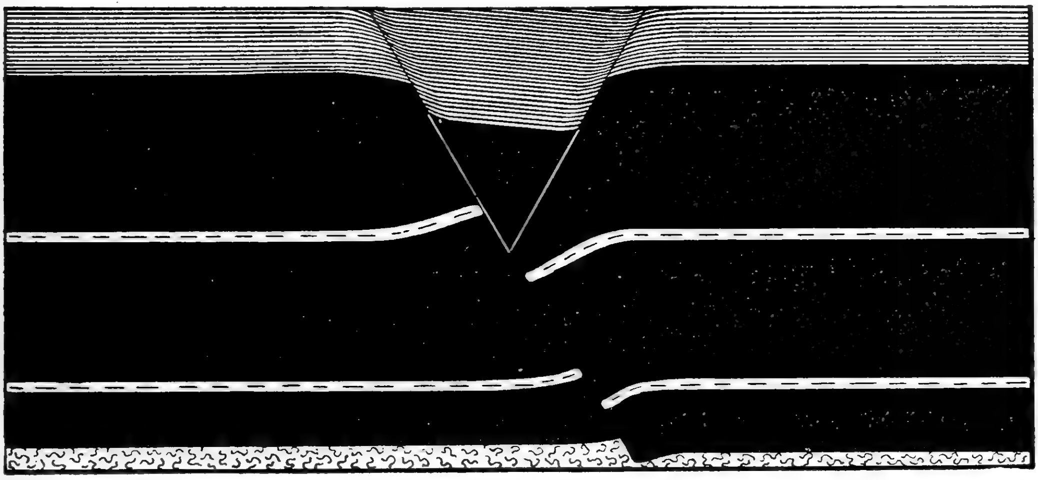

FIGURE 5.—*Trough Fault in Appanoose Shaft, southern Iowa.*

the strain has evidently been relieved partly through a major slip and partly through a minor one.

*Clay Seams.*—Simple fissures or ruptures are of not infrequent occurrence in the Coal Measures of Iowa. They are merely a separation of the different parts of the vein without apparent displacement. The

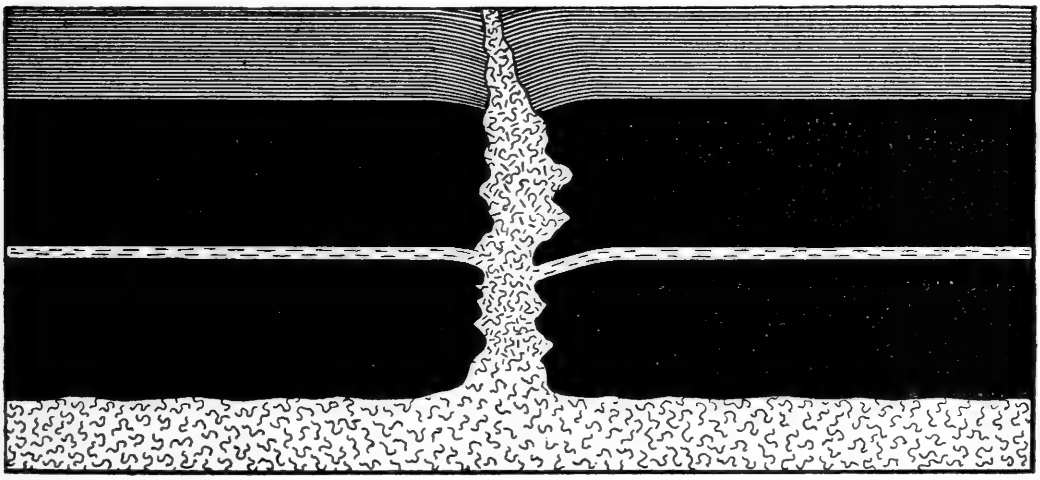

FIGURE 6.—*Clay Fissure in Thistle Mine, Appanoose County, Iowa.*

fissures are usually more or less vertical, with often very irregular borders, though sometimes they may be inclined at considerable angles. In the majority of cases clay fills the fissures which may be from a few inches to a foot or more in width, or sand may occupy all the space

and form a compact sandstone wall. One of these from the Thistle mine in Appanoose county is shown in figure 6.

*Origin of the Faults.*—While many of the displacements in the region under consideration are undoubtedly due to the ordinary causes producing normal faulting, there are some cases in the Coal Measures, and perhaps these form the majority of the small slips, which owe their origin to the gradual compression of the coal beds themselves after the original vegetable accumulations had been covered by sediments. The process of compression is probably in progress at the present time, though slowly and at a greatly diminished rate compared with the former periods.

When a vegetal mass is subjected to conditions favorable to the formation of mineral fuel in the way that most of the coal beds of the upper Mississippi valley were apparently formed, there is a constant addition of sediments above, increasing the superincumbent weight until it frequently becomes something enormous; the temperature of the mass at the same time gradually rises. The heat and pressure, aided at times by other agencies perhaps, may continue to be operative for long periods, the plant accumulation in the meanwhile going successively through all stages of bituminization to the hardest anthracite or even to graphite. In the process, through the loss of water and various gases and through certain chemical reactions of the various component elements or compounds among themselves, the bulk of the mass is very greatly reduced, the amount of reduction of course depending upon the nature of the swamp materials, the degree of bituminization and method by which the loss of carbon is effected. According to the estimates of Maclaren, in one of the Scottish coal-fields, it would take nearly 2,000 acres of forest to produce an acre of coal three feet in thickness. In case of the average Iowa coal bed, it has probably taken upward of thirty feet of closely compacted material of the original woody growth to produce a seam of coal having the thickness of four and one-half feet—the mean measurement of the veins mined in the state. Ordinary anthracite probably shrinks to less than one-tenth of its original bulk in the course of its formation, so that a bed 25 feet thick may represent between 250 and 300 feet of the original mass.

In the diminution of bulk in a great lenticular deposit of vegetation, the change in dimensions is chiefly in a vertical direction. Providing the surface of the marsh were originally nearly horizontal, as probably was usually the case, the margins would remain stationary, while the center of the mass, where the contraction is naturally greatest, would be depressed below the level of the borders, producing, when fully compressed, a shallow, saucer-shaped sheet of coal. This fact is also well exhibited in the coal deposits of Iowa, especially in the case of the smaller basins;

as, for instance, the vein displayed at the top of the Redrock sandstone quarry in Marion county.

As an example of what took place during the period when coal was forming, a case may be assumed somewhat similar to that just mentioned. Let there be imagined a swamp one-fourth to one-half a mile in diameter and 200 feet in depth; let the swamp be filled to within a few feet of the water-level with half decayed vegetation; let the region, after this stage is reached, become one of slow subsidence, and let it be so situated as to allow the introduction into the swamp of currents, which sweep in sediments of different kinds; then the conditions of the old coal marshes are practically reproduced. If the superincumbent sediments should continue to accumulate and the peat-like mass be compressed to one-tenth or less of the original bulk the process would be almost identical with that which seems to have taken place in connection with many of the coal beds of Iowa. It being possible for the compression and diminution of bulk to take place only in one direction, that is, vertical, on account of the weight of the overlying beds, there results a broad sheet of pressed vegetal remains, thickest centrally, and becoming gradually attenuated toward the margins. During the process of compression the central part of the upper surface, which, just prior to the influx of sediments when the swamp had reached its greatest development and expansion, was on a level with the margins, is little by little depressed or bent downward as the plant remains are more and more compacted. At the end of the process the upper surface of the plant mass at the center of the basin will be from 175 to 185 feet below its original level. In the particular case assumed this would be a slope of about 1 in 13 in all directions toward the center, or a dip of 5°, nearly. Conceiving this area to be covered to a considerable depth with other beds, the phenomena becomes practically identical with what is now observed everywhere in connection with the coal beds. When the lower and more extensive seams of the Coal Measures are constantly contracting in bulk the series higher up and the associated strata, in responding to the effects of gravity, become undulatory or give rise to a series of small slips. This fact may, after more extended investigation, come to have an important economic bearing in the detection of valuable coal beds at lower levels than are commonly worked or prospected.

## Summary.

From the foregoing it would appear that—

In the upper Mississippi valley there exist faults, the number and extent of which has never been fully realized.

In the Coal Measures of some parts of the region the slips are usually of small extent, but much more numerous than has been generally suspected heretofore.

There are also numerous dislocations, but without marked displacement.

In the case of many of the small faults the stresses may have been superinduced by the diminution in bulk of lenticular coal beds at horizons somewhat lower than those in which they occur.

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# AGE OF THE AURIFEROUS SLATES OF THE SIERRA NEVADA

BY JAMES PERRIN SMITH

(*Presented before the Society December 29, 1893*)

CONTENTS



## INTRODUCTION.

During the autumn of 1893 the writer spent five weeks in field work on the Auriferous slates of the Sierra Nevada, chiefly in Plumas, Butte and Calaveras counties, California, in the effort to find some definite horizons that might be identified by fossils. In this he was greatly aided by Mr James E. Mills, under whose guidance he visited many of the localities mentioned in this paper. To Mr Mills is due in great measure whatever success was achieved by the investigations.

The Auriferous slates have long been a puzzle to California geologists, and, on account of the scientific as well as economic interest attached to them, much has been written—hardly any two writers agreeing—about their age.

This paper is intended to present the facts known at the present time.

## Opinions of previous Writers.

1858. The first geologist to write about the age of the Auriferous slates of the Sierra Nevada was W. P. Blake,* who stated that a great part of the gold-bearing formation would probably prove to be Silurian and Devonian.

1859. Sir R. Murchison also thought that these rocks were Paleozoic, mostly Silurian.† The work of Dr John B. Trask ‡ in finding Carboniferous fossils in the metamorphic rocks of Shasta county seemed to confirm these opinions, for the McCloud river rocks are almost in the prolongation of the strike of the Auriferous slates of the Sierra Nevada. L. Simonin § claims to have found trilobites in the slates, but does not give the locality. J. Marcou || says that they were found in Mariposa county, and were preserved in the museum of the University of Santiago, Chile.

1864. The first reference of the Auriferous slates to other than Paleozoic age was made by J. D. Whitney,¶ who said that they consisted largely of Trias and Jura. This was based on the finding of undoubted Triassic and Jurassic fossils in Indian valley, Plumas county, and of rather uncertain Jurassic fossils on the Mariposa estate, Mariposa county.

1865. F. B. Meek afterward published ** descriptions and figures of the Jurassic fossils of the Mariposa slates. Whitney †† refers to the finding of *Goniatites* (*Celtites?*) *lævidorsatus*, Gabb (not Hauer), in Tuolumne county between Knight's and Robinson's ferries on Stanislaus river, at the mouth of Mormon creek, and in Eldorado county at Spanish Flat. On this evidence, together with the finding of Upper Trias near Taylorsville, Plumas county, he refers part of the Auriferous slates to the Trias.

1870. W. M. Gabb‡‡ published the opinion that all the Jurassic deposits of the Sierra Nevada and their vicinity were probably of Liassic age.

1876. J. F. Whiteaves §§ thinks that *Aucella erringtoni* is the equivalent

* Pacific Railroad Report, 1858, Introduction, p. iv.

† Murchison: "Siluria," third edition, 1859, pp. 455 and 475.

‡ Report on the Geology of the Coast Mountains, 1855.

§ Comptes Rendus, tome L, 1860, p. 391.

|| Bull. Soc. Geol. France, 1883, p. 409.

¶ Am. Jour. Sci., September, 1864, p. 261.

** Geology of California, vol. i, Appendix B.

†† Paleontology of California, vol. i, p. 279.

‡‡ Am. Jour. Conch., vol. v, p. 5.

§§ Geol. Survey of Canada, Mesozoic Fossils, vol. i, part i, p. 86.

of *A. piochi*, and that the Auriferous slates are possibly Tithonian, a transition from Jura to Cretaceous.

1880. On page 39 of "Auriferous Gravels of the Sierra Nevada of California," J. D. Whitney outlines the Auriferous slates as "all the metamorphic sedimentary rocks of the Sierras," and says that they are of both Triassic and Jurassic age, but that none are Cretaceous, for rocks of that age lie unconformably on the metamorphic series. He thinks also that it is doubtful whether there are any Paleozoic rocks in the series, for there is no proof that the limestones of the Auriferous slates are a continuation of those in Shasta and Butte counties. Professor Whitney also gives a section of the Auriferous slates, in which he divides them into two great divisions: the upper containing the Mariposa slates and diabase-tuff, and the lower containing mica-schists and limestones' which may be equivalent to those at Pentz ranch, Butte county, and therefore Carboniferous.

1883. J. Marcou * says the Mariposa slates are Triassic in age, and that they belong to the Rhetic, or zone of *Avicula contorta;* also that *Ammonites colfaxi* is of Triassic type.

1884. J. F. Whiteaves † says that certain so-called Jurassic rocks (*i. e.*, the Mariposa slates) may be Cretaceous and not Jura. The same he thinks is true of the Jura of the Black hills, and most of the other so-called Jura in the west.

1885. C. A. White ‡ says that *Aucella erringtoni* and *A. piochi* are equivalent, and that part of the Auriferous slates are thus of Knoxville (Neocomian) age. Another part he thinks may be of Paleozoic age. He concludes that if all the Aucella-bearing rocks are Neocomian there is probably no Jura in California, as all the so-called Jura is probably equivalent.

1886. J. S. Diller § says that the auriferous slates are part Carboniferous and part Mesozoic.

1888. G. F. Becker || discusses the relations of the Mariposa slates to the Knoxville, and concludes they are identical, because of the supposed identity of *Aucella erringtoni* and *A. piochi*, no other supposed Shasta species being found in the Mariposa slates. Doctor White ¶ discusses the age of the Aucella-bearing beds of the Coast range, classes them with the Neocomian, and says that the Aucella beds of the Auriferous series—that is, the Mariposa slates—are their equivalents.

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* Bull. Soc. Geol. France, 1883, p. 410.

† Geol. Survey Canada, Mesozoic Fossils, vol. i, part iii, pp. 260–261.

‡ Bull. 15, U. S. Geol. Survey, pp. 24–26.

§ Bull. 33, U. S. Geol. Survey, p. 16.

|| Monograph xiii, U. S. Geol. Survey, pp. 198–204.

¶ Monograph xiii, U. S. Geol. Survey, Appendix to chapter v.

1891. G. F. Becker* concludes that the Mariposa slates are Gault. H. W. Fairbanks † says that the evidence is in favor of the Jurassic age of the Auriferous slates and the limestones associated with them.

1892. James E. Mills ‡ gives about the same stratigraphy of the Sierra Nevada rocks as that given by Whitney,§ and refers one portion of the series to pre-Mesozoic time; another to Lower Mesozoic, on the evidence of the occurrence of *Pentacrinus* and *Ammonites colfaxi*, both supposed to be indicative of Jurassic age, and a third portion he refers to Upper Mesozoic from supposed equivalence with the Mariposa slates.

1893. G. F. Becker || divides the Auriferous slates series into the Calaveras formation and the Mariposa formation. The Calaveras formation is to include all the Paleozoic deposits of the Sierra Nevada, except the Silurian, described by J. S. Diller, from Plumas county,¶ and afterwards named the Grizzly formation.**

The Mariposa formation makes up the upper division of the Auriferous series. None of the supposed Triassic of the Sierra Nevada comes within this sheet, but similar ones at the northern end of those mountains have been named the Cedar †† formation.

H. W. Turner ‡‡ gives several localities for Carboniferous and Mesozoic fossils in the Auriferous slates series, but does not give any exact horizon.

## Determined Horizons and well-known Fossil Localities.

In presenting the results of the investigations it seemed best to the writer to give in tabular form all the known localities for fossils in the metamorphic series, and then to follow with a discussion of those occurrences about which new information could be added.

## Review of recent Discoveries and Determinations of Fossils.

### *CARBONIFEROUS LOCALITIES.*

*Longville, Plumas County.*—This locality, which is near the town of Longville, was first mentioned by J. S. Diller,§§ who found there *Lithostrotion whitneyi*, Meek, *Lophophyllum proliferum* (?) and a Spirifer (?). In a later paper |||| he refers to this locality again, and quotes C. D. Walcott

* Bull. Geol. Soc. Am., vol. 2, pp. 189–208.
† Am. Geologist, vol. vii, p. 219.
‡ Bull. Geol. Soc. Am., vol. 3, pp. 413–444.
§ Auriferous Gravels, pp. 44–49.
|| Geological Atlas, U. S. Geol. Survey, Sacramento Sheet.
¶ Bull. Geol. Soc. Am., vol. 3, 1892, p. 376.
** Geological Atlas, U. S. Geol. Survey, Lassen Peak Sheet, 1892, J. S. Diller.
†† Geological Atlas, U. S. Geol. Survey, Lassen Peak Sheet, 1892, J. S. Diller.
‡‡ Am. Geologist, vol. xi, pp. 307–324.
§§ Bull. 33, U. S. Geol. Survey, p. 11.
|||| Bull. Geol. Soc. Am., vol. 3, p. 375.

on the probability of this being Lower Carboniferous. The writer visited the place in October, 1893, and collected *L. whitneyi*, *Fusulina cylindrica*, *Eumetria*, *Spirifer cameratus* (?), *Aviculopecten* (?), *Conocardium* (?) and many round crinoid stems. In diabase-tuff just above the limestone was found a *Productus*, possibly *P. semireticulatus*. This fauna is probaqly equivalent to that of the upper part of the McCloud river imestone, which lies a thousand feet or more above the Lower Carboniferous siliceous shales of Baird, Shasta county, and thus would in all probability represent the lower part of the Coal Measures.

*Spanish Creek and Clermont Peak*, *Plumas County*.—A letter from Mr H. W. Turner, September 13, 1893, says that Mr T. W. Stanton has collected *Fusulina cylindrica* and other Carboniferous forms from a locality on Spanish creek one mile east of Spanish ranch; also corals, et cetera, probably Paleozoic, from the limestone on Rock creek, about a mile and a half northwest of summit of Clermont peak. The writer visited these localities, and on Spanish creek found *Lithostrotion whitneyi*, *Favosites*, *Campophyllum* (?) and numerous round crinoid stems. On Rock creek he found a *Campophyllum* and crinoid stems. There can be no doubt that both localities are of Carboniferous age.

*Bear Mountain*, *Calaveras County*.—H. W. Turner* says that the United States Geological Survey has found *Fusulina cylindrica*, *Zaphrentis*, and round crinoid stems in the limestone of Bear mountain and in the continuation of this belt northward. In November, 1893, the writer found also a *Michelinia* in the limestone of a quarry on A. R. Young's place, five miles northeast of Valley springs. James E. Mills also collected a *Zaphrentis* from a quarry in township 5 north, range 11 east, section 32, northeast quarter of southeast quarter, on the road between Campo Seco and Mokelumne hill.

*Pentz Ranch*, *Butte County*.—J. D. Whitney † assigns these limestones to the Carboniferous, while James E. Mills ‡ refers them to the lower Mesozoic, but without any paleontologic evidence. The writer failed to find any brachiopods, but found a *Favosites* and *Archæocidaris*, and numerous very large round crinoid stems which resemble *Poteriocrinus*.

### *TRIASSIC LOCALITIES.*

*Oscar Tunnel*, *Plumas County*.—J. S. Diller § includes this locality in his Cedar formation, the equivalent of the Hosselkus limestone, Upper Trias, of the Genesee valley. In a letter of August 13, 1893, Mr Diller announces the discovery of *Ammonites*, *Pentacrinus* and other fossils in

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* Am. Geologist, vol. xi, p. 309.
† Geol. of California, vol. i, p. 210.
‡ Bull. Geol. Soc. Am., vol. 3, p. 434.
§ Geol. Atlas, U. S. Geol. Survey, Lassen Peak Sheet.

*Table of Fossil Localities in the Auriferous Slates of the Sierra Nevada.*

| Locality and horizon. | Authority and reference. | Age as determined by fossils. |
|---|---|---|
| SILURIAN. | | |
| Plumas county, Grizzly peak | J. S. Diller, Bull. Geol. Soc. Am., vol. 3, p. 376. | Niagara. |
| CARBONIFEROUS. | | |
| Plumas county, Genesee valley | J. D. Whitney, Geol. Cal., vol. i, p. 308; J. S. Diller, Bull. Geol. Soc. Am., vol. 3, p. 375. | Upper Carboniferous. |
| Plumas county, near Humbug valley, between Yellow and Mosquito creeks. | J. S. Diller, Bull. Geol. Soc. Am., vol. 3, p. 375. | Probably Upper Carboniferous. |
| Plumas county, 2½ miles west of Quincy; also 1½ miles northwest of Clermont peak. | H. W. Turner, letter of Sept. 13, 1893 | Carboniferous; horizon uncertain. |
| Plumas county, Onion valley creek | H. W. Turner, letter of Sept. 13, 1893 | Carboniferous; horizon uncertain. |
| Butte county, Pentz ranch | J. D. Whitney, Geol. Cal., vol. i, p. 210 | Carboniferous; horizon uncertain. |
| Butte county, Chico canyon, 16½ miles east of Chico. | J. S. Diller, Bull. 33, U. S. Geol. Survey, p. 11. | Carboniferous; horizon uncertain. |
| Amador county, Strickland ranch, near Sutter creek. | Mus. State Min. Bureau, no. 11949 | Uncertain; only round-stemmed crinoids found. |
| Amador county, McCormick ranch, near Volcano. | Mus. State Min. Bureau, no. 11948 | Uncertain; only round-stemmed crinoids found. |
| Amador county, Malson's ranch, near Drytown. | Mus. State Min. Bureau, no. 11952 | Uncertain; only round-stemmed crinoids found. |
| Calaveras county, Bear mountain | H. W. Turner, Am. Geologist, vol. xi, p. 309. | Carboniferous, *Fusulina*, etc. |
| Calaveras county, Cave City | Mus. State Min. Bureau, no. 11950 | Uncertain; only round-stemmed crinoids found. |
| Mariposa county, Hite's cove | H. W. Turner, Am. Geologist, vol. xi, p. 309. | Carboniferous, *Fusulina*, etc. |
| TRIASSIC. | | |
| Plumas county, Genesee valley | W. M. Gabb, Pal. California, vol. i; J. S. Diller and A. Hyatt, Bull. Geol. Soc. Am., vol. 3, pp. 369–417. | Upper Trias, Noric and Karnic. |

| | | |
|---|---|---|
| Plumas county, Oscar tunnel, Humbug valley. | J. S. Diller, letter of Aug. 13, 1893....... | Upper Trias, Karnic (?). |
| Plumas county, Rush creek mine............ | J. E. Mills, Bull. Geol. Soc. Am., vol. 3, p. 428. | Upper Trias, Karnic and Noric (?). |
| Eldorado county, Spanish flat............... | J. D. Whitney, Geol. Cal., vol. i, p. 279.. | Very uncertain. |
| Tuolumne county, Mormon creek, near Robinson's ferry. | J. D. Whitney, Geol. Cal., vol. i, p. 234.. | Very uncertain. |
| Tulare county, Mineral King district......... | G. F. Becker, Bull. Geol. Soc. Am., vol. 2, p. 206. | Certainly Trias; exact horizon not given. |
| JURASSIC. | | |
| Plumas county, Indian valley............... | Geol. Cal., vol. i, and Pal. Cal., vol. i; J. S. Diller and A. Hyatt, Bull. Geol. Soc. Am., vol. 3, pp. 369–412. | Lias to Corallian. |
| Sierra county, three-quarters of a mile east of Sierra City. | Collection of Mr J. E. Mills............. | An ammonite that looks like Jura; very uncertain. |
| Placer county, Sailor canyon................ | Mus. State Min. Bureau................ | An ammonite resembling *A. colfaxi*; very uncertain. |
| Placer county, Colfax .................. .. | W. M. Gabb, Am. Jour. Conchol., vol. v, p. 7; J. D. Whitney, "Auriferous Gravels," p. 37. | Possibly Lias, but uncertain. |
| Eldorado county, Wilkinson's ranch......... | J. D. Whitney, "Auriferous Gravels," p. 37. | Possibly Lias, but uncertain. |
| Eldorado county, Huse bridge, on Cosumnes river. | Collection of Mrs M. J. Gates........... | Ammonite, like *A. colfaxi*; possibly Lias, but uncertain. |
| Calaveras county, 2 miles north of Campo Seco. | H. W. Turner, Am. Geologist, vol. xi, p. 308. | Uncertain. |
| Calaveras county, 2 miles west of Angels...... | H. W. Turner, Am. Geologist, vol. xi, p. 308. | Uncertain. |
| Calaveras county, Texas ranch, 6 miles east of Copperopolis. | H. W. Turner, Am. Geologist, vol. xi, p. 308. | Upper Jura; probably lower Kimmeridge, as determined by the writer. *Aucella erringtoni* and *Cardioceras alternans*. |
| Mariposa county, Mariposa estate........... | Geol. Cal., vol. i, p. 226, and Appendix B; J. D. Whitney, "Auriferous Gravels," p. 37; Am. Jour. Sci., September, 1864, p. 261; W. M. Gabb, Am. Jour. Conchol., vol. v, p. 5. | Upper Jura; probably lower Kimmeridge. |
| Inyo county, east of the Sierra Nevada....... | A. Hyatt, Bull. Geol. Soc. Am., vol. 3, p. 411. | Lias, with *Vermiceras* and *Arnioceras*. |

the Trias of this region. The writer visited this locality in October, 1893, and found *Pentacrinus*, *Encrinus* (?) *Spiriferina and Attractites.* The evidence is therefore sufficient to place these rocks in the upper part of the Trias, probably Karnic.

*Rush Creek Mine, Plumas County.*—J. S. Diller* includes this limestone in his Cedar formation, basing his conclusions on the Triassic fossils he found there.

James E. Mills † published the first notice of the occurrence of *Pentacrinus* in these beds, and called them Jurassic or later, upon the opinion of Dr Charles Wachsmuth, who thought that this type of crinoids did not antedate the Jurassic. *Pentacrinus*, however, is well known to occur in the Trias in Europe, and has been found in rocks of that age in three other places in California, associated, as in this case, with undoubted Triassic fossils.

In October, 1893, the writer visited this locality in company with Mr Mills, and found numerous characteristic Upper Triassic fossils of the horizon of the Hosselkus limestone. At the top of the series was seen diabase-tuff with pebbles of granitoid rock. Below this were several feet of shaly siliceous limestone with pebbles of phthanite and granitoid rock, *Pentacrinus*, *Cidaris*, *Spiriferina* and an undescribed species of *Tropites*, identical with specimens collected in Shasta county. Below the Pentacrinus limestone are seen dark, very thin bedded shales, which, where not too much altered, showed *Attractites* and *Halobia superba* (?), *Daonella* (?), and *Avicula.* This fauna is identical with that described by A. Hyatt ‡ from the Genesee valley, and also with that found by H. W. Fairbanks between Squaw creek and Pit river, Shasta county. It is of Karnic age of the Upper Trias, and the stratigraphy agrees with that of Plumas and Shasta counties, where the Halobia slates underlie the Hosselkus limestone.

Below the Halobia slates are about 1,500 feet of siliceous, dark shales and tuffs, very much like the underlying shales of Shasta county, where they are known from fossils to be in part of Triassic age, probably Noric. In the Rush creek region no fossils were found in them. Next to the shales is a large mass of serpentine, but it is not known whether it is conformable or not, or whether it underlies them.

### *JURASSIC LOCALITIES AND FAUNA.*

*Texas Ranch, Calaveras County.*—This locality, which is on the ranch of Charles Grossman ("Texas Charlie"), is in the valley of Angels creek,

* Geol. Atlas, U. S. Geol. Survey, Lassen Peak sheet, 1892, top of third column of descriptive text.
† Bull. Geol. Soc. Am., vol. 3, p. 428.
‡ Bull. Geol. Soc. Am., vol. 3, pp. 395–412.

500 yards north of the Sonora stage road. It has been known for several years, but the only published mention of it was made recently by H. W. Turner,* who notes the occurrence of aucellæ and ammonites in the slates. In 1893 James E. Mills sent to the writer some fossils from this locality, including an Aucella, a Pecten, an ammonite and fragments of wood.

In November, 1893, the writer visited the region and noted that east of Copperopolis is a large thickness of diabase-tuff, interbedded with crystalline limestone, which is best seen about four miles east of Copperopolis. The limestone strikes northwest-southeast, and shows traces of fossils, but they could not be determined. East of the diabase-tuff and limestone is a considerable thickness of serpentine, and still further east is a thickness of several hundred feet of finely laminated slates, interbedded with conglomerates and some serpentine. On the stage road to Sonora about six miles east of Copperopolis and on the east slope of Bear mountain are found a few aucellæ, and in the valley, at the Texas ranch locality previously described, the slates are seen again in places with many fossils—lamellibranchs and cephalopods. The fauna is a very interesting one and characteristic of Upper Jurassic and of either Corallian or lower Kimmeridge age.

*List of Fossils.*—The following is a systematic list of the fossils found here:

### *BRACHIOPODA.*

*Rhynchonella*, sp.

One specimen, not in a condition to figure, seems to present the characteristics of *Rhynchonella*, but is so flattened that no certain determination could be made. It resembles somewhat *Rhynchonella myrina*, Whitfield. Geology of the Black Hills of Dakota, p. 347, pl. III, figs. 6, 7.

### *LAMELLIBRANCHIATA.*

*Amussium (Entolium) aurarium*, Meek. Geol. of California, vol. i, p. 478, pl. I, fig. 6.

*Lima*, sp.

A small Lima, with heavy, radiating ribs, was found, but could not be determined specifically.

*Aucella erringtoni*, Gabb.

*Lima erringtoni*, Gabb. Proc. California Acad. Sci., November, 1864, p. 173.

*Aucella erringtoni*, Gabb, F. B. Meek. Geol. of California, vol. i, p. 479, pl. I, figs. 1, 2, 3, 5, 7.

* Am. Geologist, May, 1893, p. 308.

*Aucella concentrica*, Fischer, Dr C. A. White. Monograph XIII, U. S. Geol. Survey, p. 230, pl. IV, figs. 6–10.

This species, whose affinities were first recognized by Meek, occurs in great numbers in the slates at Texas ranch in all stages of compression and distortion, so that specimens may be obtained showing all the variations figured by Meek, and many others also.

C. A. White* unites *A. erringtoni*, Gabb, with *Aucella piochi*, Gabb, of the Knoxville group, Neocomian, and with *A. pallasi*, Keyserling, and *A. mosquensis*, von Buch of the Upper Jura of Russia, and *A. crassicollis*, Keyserling of the Lower Cretaceous, Neocomian, of Russia. But it has been shown by Lahusen† that the Russian species are not all the same, but are well characterized, and are found in very different horizons and with different faunas, and thus themselves become in a measure index-fossils. Lahusen‡ has represented this in a table, dividing the Russian Upper Jura and Lower Cretaceous into zones on the basis of the occurrence of the various species of *Aucella*. Thus *Aucella pallasi*, Keyserling, is shown to be confined to the Upper Jura and to range from the upper Oxford to the lower Portland; *A. mosquensis*, von Buch, ranges from the middle Portland into the lower portion of the upper Portland, while *A. crassicollis*, Keyserling, is confined to the Lower Cretaceous, Neocomian, and is very similar to if not identical with *A. piochi*, Gabb, of the Knoxville. *Aucella concentrica*, Fischer, is not recognized by Lahusen, because Fischer de Waldheim described under that specific name several different species from different horizons ranging from Oxford to Neocomian. It therefore becomes extremely improbable that all the American species of *Aucella* are identical with each other, since they have been based on this hybrid species. Meek, in his description of *A. erringtoni*, Gabb,§ notes the similarity to *A. pallasi*, Keyserling, and says they are very possibly identical. Lahusen, in his monograph,|| also notes the resemblance between left valves of *A. erringtoni* and *A. pallasi*, and on page 33 of the same work he compared the right valves of *A. erringtoni* and *A. bronni*, Rouiller, the only difference between them being that on the California species the radial lines are very distinct only on the anterior part of the shell. But in the collection from Texas ranch are numerous specimens that have the radial lines just as strong on the posterior as on the anterior part of the shell, and some even stronger. It thus becomes probable that *A. erringtoni*, Gabb, represents in reality the two species, *A. pallasi*, Keyserling, and *A. bronni*, Rouiller, which, because of the state of preservation, we are not now able to distinguish from each other.

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* Monograph xiii, U. S. Geol. Survey, p. 230.

† Mém. Com. Géol. (Russia), 1888, vol. viii, no. 1, "Ueber Russische Aucellen."

‡ Op. cit., p. 26.

§ Geol. of California, vol. i, p. 480.

|| Mém. Com. Géol., vol. viii, no. 1, p. 35.

## *CEPHALOPODA.*

*Belemnites pacificus*, Gabb. Proc. Cal. Acad. Sci., Nov., 1864, p. 173.

This species has never been figured from California, but one from Alaska supposed to be identical with it has been described by C. A. White* as associated with *Aucella*. In the slates at Texas ranch a few specimens were found, but too imperfect to be satisfactorily identified.

*Cardioceras alternans*, von Buch.

*Ammonites alternans*, L. von Buch, Gesammelte Werke, vol. iv, p. 454, pl. 18, fig. 4.

*Ammonites alternans*, Quenstedt. Ammoniten des Schwäbischen Jura, p. 824, pl. 91, figs. 1–25.

This species is a very variable one, and probably not all the varieties united by Quenstedt are the same; still this group of *Cardioceras* is well marked and easily distinguished from that of *C. cordatum*, Sowerby, and *C. cordiforme*, Meek and Hayden. This species differs from *C. cordiforme*, Meek and Hayden,† in having the sides less arched and the involution less; also on *C. cordiforme* the ribs are more numerous and usually each alternate rib forks at the umbilicus and swings with a gentle curve forward, nowhere showing a tendency to produce knots. In *C. alternans* the ribs fork with great irregularity, sometimes each alternate one and sometimes the third or fourth. They fork about half way to the outside or ventral portion of the shell, forming usually a small knot at the fork, and often forming a second one where the ribs make their sickle-shaped bend forward on the external side.

The very high, sharp, strongly serrated keel is characteristic of this species.

The specimens are all distorted from the crushing of the slates, and thus are elliptical instead of spiral, but they show the same amount of involution as that given on the figures of Quenstedt. The umbilicus is much wider and less deep than that of *C. cordiforme*, Meek and Hayden, or *C. cordatum*, Sowerby.

The body chamber is about one coil in length.

A closely related species has been described by Pavlow ‡ under the name *Cardioceras volgæ*, Pavlow, of the zone of *Aspidoceras acanthicum*, lower Kimmeridge, but that species is much more involute than the California specimens, while the fineness of the costæ is about the same.

*Cardioceras subtilicostatum*, Pavlow,§ is still more closely related to our species, but is also more involute. It may be identical with a variety of

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* Bull. 4, U. S. Geol. Survey, p. 14, pl. vi, figs. 13, 14.

† Pal. Upper Missouri, p. 122, pl. v, fig. 2.

‡ Mém. Com. Géol. (Russia), vol. ii, no. 3, p. 86, pl. viii, fig. 5.

§ Op. cit., p. 86.

*C. alternans* described by P. de Loriol.* Thus the Russian and the Californian specimens may represent extremes of the same species. If this Californian species should not be identical with *C. alternans*, I would suggest the name *Cardioceras whitneyi* for it.

*Cardioceras alternans* is confined to the upper Oxford in Germany, but in Switzerland and in Russia ranges up into lower Kimmeridge—that is, into the lower part of the zone of *Aucella bronni*. Thus the beds containing this fossil must be of Upper Jurassic age and between the upper Oxford and the middle Kimmeridge. The accompanying *Aucellæ* being closely related to both *A. bronni* and *A. pallasi* makes it probable that they belong to the higher part of the series, that is, to the lower Kimmeridge.

*Perisphinctes* (?).

One fragment in the slates is entirely different from the common *Cardioceras*, and seems to have the characteristics of *Perisphinctes*, but it is very doubtful.

The fauna of the slates of Texas ranch, Calaveras county, is plainly the same as that of the Mariposa slates, and any evidence of the age of the one applies to the other also.

## Mariposa Slates.

In the first part of this paper the opinions of various writers have been given as to the age of the Mariposa slates, which, upon supposed paleontologic evidence, have been assigned to various periods, ranging from the Trias to the Gault; but from what has been said of the slates at Texas ranch it is seen that the Aucella beds of Mariposa are of the age originally assigned to them by Gabb,† although Meek recognized their position more accurately by comparing the *Aucella* ‡ to a European species of known position.

There can no longer be any doubt that the Mariposa beds belong to the lower part of the Upper Jura, and are thus probably the youngest Jurassic deposits known in North America, with the possible exception of the Corallian described from mount Jura, Plumas county, by A. Hyatt. §

Professor Hyatt || shows that the Jura of the Black hills and adjoining regions belongs to the Callovian or lower Oxford, but that in that time

* Abhandl. Schweizer Paläont. Gesell., vol. iii, "Monographie Zone *A. tenuilobatus* de Baden," p. 20, pl. i, figs. 17 and 18.

† Proc. California Acad. Sci., vol. iii, p. 172.

‡ Geol. of California, vol. i, p. 479.

§ Bull. Geol. Soc. Am., vol. 3, p. 408.

|| Op. cit., p. 409.

there was probably no direct connection between the Californian Upper Jurassic deposits and those of the interior.

M. Neumayr* has shown the possibility of some of the so-called Lower Cretaceous of British Columbia being Jurassic, and if so, it would be very much higher, that is, Portland.

## Russian Aucella-bearing Rocks.

Since the confusion as to the age of the Mariposa slates originated from a mistake as to the age of the Aucella-bearing beds of Russia, a few words about these strata may not be out of place.

The earlier geologists united the younger Mesozoic deposits of Russia under the name "Wolga Stage," which most of them thought to be Upper Jurassic, although some of them, among whom Eichwald was chief, recognizing Cretaceous affinities in some of the fossils, declared the Wolga stage to be Cretaceous.

Professor Whiteaves † has gone still further and declared all the Aucella-bearing rocks of Europe and America to be Cretaceous. This view has been emphatically rejected by Neumayr ‡ and Doctor White;§ but there never was any controversy as to the Jurassic age of the zones of *Cardioceras cordatum* and of *C. alternans*, which were always recognized as belonging to the Kelloway-Oxford and Oxford-Kimmeridge respectively. In these zones are found several species of *Aucella*.

The later works ‖ of Pavlow, Nikitin, Lahusen, Michalski and others have shown that the Wolga stage is not a unit, but may be divided into two distinct horizons—the lower Wolga stage, which corresponds to the lower and middle Portland, and the upper Wolga stage, which corresponds at the base to upper Portland, and at the top to Neocomian. The correlation of these deposits has been materially advanced by the comparison of the Speeton clays of England with the upper Wolga stage of Russia, by Pavlow¶ and Lamplugh, in which numerous species are cited as being characteristic of the same horizons in the two countries; among these may be mentioned *Aucella pallasi*, Keyserling, which is said by Nikitin** to be the same as *Avicula vellicata*, Blake, of the lower Portland or Bolonian stage.

Doctor White †† admits that *Aucella* may have been a Jurassic genus

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* Denk. K. Akad. Wiss., Wien, 1885, p. 96.

† Geol. Surv. Canada, 1884, Mesozoic Fossils, vol. i, part i, pp. 258–261.

‡ Geograph. Verbreitung Jura, p. 96.

§ Am. Jour. Sci., vol. xxix, 1885, p. 228.

‖ For a résumé of the literature of this subject, see A. Pavlow, Bull. Soc. Impér. Nat. Moscow, 1889, no. 1, "Jurassique Supérieur et Crétacé Inférieur de la Russie et de la Angleterre."

¶ Bull. Soc. Impér. Nat. Moscow, 1891, nos. 3 and 4.

** Bull. Soc. Impér. Nat. Moscow, 1889, no. 1, p. 38.

†† Monograph xiii, U. S. Geol. Survey, p. 229.

in Russia, and thinks that the time consumed in migrating from Russia to America might explain its occurrence in Cretaceous rocks in America.

But now it becomes just as possible that they migrated the other way, since we have *Aucella* in California in rocks of probably as great age as any in Russia. In fact, it becomes more probable when we consider the fact that in a country so near to Russia as England *Aucella* did not appear until lower Portland time.

## Application of Neumayr's Theory of climatic Zones.

M. Neumayr refers the Jura of California * and Nevada to the middle European type, while admitting that there were some Arctic elements, such as *Aucella*. The Jura of the Black Hills † he refers to the boreal type, on account of the occurrence of *Cardioceras*.

In a later work ‡ Neumayr says that the California Jura shows a commingling of boreal with temperate zone types, because the two oceans joined in this region, and that it was separated from the Black hills region by a strip of land.

Professor Hyatt § has shown that the Upper Jura of Plumas county is of central European type, and that it was separated from that of the Black hills district. We have, then, in Calaveras and Mariposa counties a boreal type of Jura about 160 miles south of a temperate zone type. Something similar was recently observed by Dr A. Tornquist || in the Jura of East Africa, where he found that the distribution of Jurassic forms could not be explained upon the supposition of parallel climatic zones, but rather upon the theory of separate provinces, that is, of more or less separated sea-basins in which, individually, of course, climate will show its effects.

The Jura of Mariposa is boreal if that of the Black hills region is, for it contains even more Arctic elements.

## Metamorphic Rocks of the Coast Range.

J. D. Whitney ¶ considered the metamorphic series of the Coast range to be of Cretaceous age from the supposed continuity of unaltered Cretaceous with the jaspers.

Doctor Becker ** followed Professor Whitney for the same reasons.

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* Ueber Klimatische Zonen während der Jura und Kreide Zeit, Denks. K. Akad. Wiss., Wien, 1883, p. 301.

† Op. cit., p. 302.

‡ "Die Geographische Verbreitung der Juraformation," Denk. K. Akad. Wiss., Wien, 1885, p. 124-5.

§ Bull. Geol. Soc. Am., vol. 3, p. 410.

|| Jahrb. Hamburg. Wiss. Anst. X 2, "Oxford fauna von Mtaru," p. 24.

¶ Geol. of California, vol. i, and "Auriferous Gravels."

** Monograph XIII, U. S. Geol. Survey.

It has been shown by J. S. Diller* and T. W. Stanton that there is no break between the Shasta and the Chico groups; therefore any metamorphism that affected the Knoxville ought to have affected the Chico also; but this is nowhere the case. Mr Diller has further shown that the uplift and metamorphism was pre-Cretaceous in the Klamath mountains and in the northern Sierra Nevada.

H. W. Turner † assumes that the metamorphic series of mount Diablo pass over into the unaltered Knoxville, but without any convincing proof, as he afterwards admits.‡

H. W. Fairbanks § says that he has traced the phthanites of the Klamath mountains into those of the Coast range, and throughout both these mountain chains has found the Knoxville beds, when present, resting everywhere unconformably on this metamorphic core of pre-Cretaceous rocks. All these writers agreed that if *Aucella* could be found in the metamorphic series, its Cretaceous age would be settled.

But from what has been said as to the age of Aucella-bearing beds in Europe it becomes plain that such is not the case. In 1892 the writer found in the metamorphic phthanite series of Alum Rock canyon near San José several aucellæ of the type *A. mosquensis*, Buch, as figured by Lahusen; ‖ also in Stevens creek canyon, about 13 miles west of Mountain View, Santa Clara county, he found in very silicious, black metamorphic shale aucellæ that agree with *Aucella trigonoides*, Lahusen.

Now these two species of *Aucella* in Russia are confined to the middle and upper Portland, of the Upper Jura. It is therefore probable that at least a part of the Coast range metamorphics are of Upper Jurassic age.

A. C. Lawson¶ accepts the pre-Cretaceous age of the Coast range metamorphics, but thinks the uplift was pre-Jurassic and that the erosion took place during the Jura.

From what has been said it is seen that the uplift and metamorphism was of late Jurassic age in at least a portion of the Coast range.

## Conclusions.

The Auriferous slates are known to consist of Silurian, Carboniferous, Triassic and Jurassic strata.

The Mariposa slates are of Upper Jurassic, probably lower Kimmeridge, age.

* Bull. Geol. Soc. Am., vol. 4, pp. 205–224 and pp. 245–256.
† Bull. Geol. Soc. Am., vol. 2, p. 394.
‡ Am. Geologist, vol. xi, 1893, p. 314.
§ Am. Geologist, March, 1892, and February, 1893.
‖ Mém. Com. Géol. Russie, vol. viii, no. i, p. 36, pl. 11, figs. 21–24.
¶ Jour. Geology, vol. i, p. 583, "The Cordilleran Mesozoic Revolution."

The uplift and metamorphism of the Sierra Nevada and of the Coast range occurred in late Jurassic time, before the deposition of the Cretaceous.

Neumayr's theory of climatic zones cannot be applied with exactness to the Jura of California, which can be understood only by the study of the geographic provinces of that time.

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# GEOLOGIC ACTIVITY OF THE EARTH'S ORIGINALLY ABSORBED GASES

BY ALFRED C. LANE

(*Read before the Society December 28, 1893*)

CONTENTS



## INTRODUCTION.

In view of the fact that one or two friends have spoken to me of this paper as propounding original theories, a word of personal explanation

may not be out of place. I claim no such originality. It is true the main outlines of this theory of igneous phenomena came into my consciousness as the result apparently of my own thinking when, in college days, I was convinced by Darwin's paper in Thomson's and Tait's "Natural Philosophy" that the earth must be regarded as rigid; but in the intervening years I found in reading along the suggested lines that almost every point had been thought out before me. Meanwhile the facts have been marshalling themselves in my mind around this theory, and in this connection I must acknowledge obligation to Neumayr's "Erdgeschichte" and to writings and conversations with numerous teachers and friends.

Nearly five years ago there was published Reyer's "Theorische Geologie," which occupies very much the same position in very many points as this paper. Directly to this book I owe but little. In fact, the argument of this paper was written and shown to Dr Wadsworth many months ago and before I had seen the book, to which I would refer, however, as a magazine of facts in support of the ideas here advanced. He also gives references to previous authors to whom the first thoughts are really due.

I have said little about these ideas during these ten years, partly for fear of hardening them by controversy from a hypothesis to a theory in my mind and partly because I was bothered to see how the fissures which the theory requires could penetrate the lower regions under the hydrostatic pressure and plasticity which there exist. The conception that the occluded gases might counteract this hydrostatic pressure is the most original point in the paper, so far as my reading has yet gone. Minor divergencies in the point of view from previous writers may also be remarked, as might be expected in largely independent work, and I flatter myself that I have marshalled several lines of facts in support of the theory whose bearing in that direction has hitherto escaped notice. The interwelding of Tschermak's theory as to the escape of occluded gases with Durocher's theory, slightly modified, as to the composition of the earth seems to me to add mutual strength. The parallelism between volcanic and blast-furnace reactions, already remarked by Bell, thus developed will lead to a fruitful line of inquiry. The tendency to obliterate the line between plutonic and volcanic rocks may be checked, and the harmonizing of igneous phenomena with those which point to a solid earth will be another stumbling block removed.

In order to reduce to a minimum the labor and library required to verify the facts referred to, I have just gone over the paper and whenever possible changed the references to the 1893 edition of Geikie's Text-book of Geology, just out, in which further details and references to the original papers may be found.

## Scope of the Paper.

*Synopsis of Argument.*—The argument of this paper is briefly as follows :

*a.* The earth in its early state absorbed various gases which now it tends to give off, having solidified in process of cooling. These gases are an original and essential factor in every igneous magma, and their retention is necessary to the crystalline development and texture of the plutonic and dike rocks, as is their sudden loss to the development of volcanic rocks.

*b.* Whenever cracks extend down into the solid earth far enough these gases escape and are the essential moving cause of volcanic eruptions by carrying with them the lava, just as champagne is carried out of a bottle by the imprisoned gas.

*c.* The earth after getting below the various surface formations gradually increases in basicity, weight and heat toward a core mainly iron.

*d.* Thus lavas first delivered from a crack will be a mixture from different levels of the earth. Their chemical composition will vary according to the depth of the crack and other casual circumstances, but will be of medium basicity as regards the material that can be furnished from the crack. Any already individualized minerals of pronounced acid or basic character, as, for example, quartz or olivine, will be corroded by the resultant magma.

*e.* Acid lavas would be furnished particularly by shallow cracks. They would have a less high temperature than the basic and be in a pasty condition. The deeper seated basic lavas would have a higher temperature and hence take a longer time to cool, and hence give their vapors more time to escape before final consolidation.

*f.* In plutonic rocks these primal absorbed gases, slowly given off after intrusion, produce in the adjacent rocks the characteristic contact-zone. In volcanic rocks the gases escape from the vent, and hence the contact-zone is of different character, if at all present.

*g.* These gases may also be concentrated in the crystallization of plutonic masses (batholites) into the pegmatite and other dikes, and assist in giving them their peculiar character, and there is a continuous series from pegmatites to segregation veins and true fissure veins filled by ascent, so that there is justification for classing the pegmatites with either veins or igneous rocks. The gases in such cases are doubtless condensed into a strongly mineralized hot water.

*h.* If the gases percolate outward in all directions with extreme slowness, we should expect them to tend to produce a regular gradation in composition from the center outward and to cause an exchange of material in alternating beds of different composition.

The gradual silicification of the older rocks and the metamorphism of the crystalline schists may be in part due to this cause, being like a contact-zone for the earth's interior.

*i.* Their activity would accentuate the crumpling of the earth's surface by abstracting material below and adding part of it to the crust.

*j.* They would affect the cooling and thermal gradient of the earth, and hence also other estimates of its age based thereon.

*Relative Importance of Points discussed.*—As to the points presented in the preceding section it should be noticed that they are not all of the same order.

The first three are primary, while the others follow from them. Yet they describe effects which, though they would naturally follow from the state of things outlined in the first three propositions, might be insignificant in quantity or overruled by other factors not taken into consideration. Indications of such effects would tend to sustain the whole body of theory, but negative results would not be at once fatal to it.

In enlarging on the evidence for these conceptions I shall not generally go into minute details which are found in the books referred to, but rather point to lines of facts familiar to the members of this Society most interested, because they have worked upon them themselves.

## Absorbed Gases.

*Given off rather than combined.*—That the earth absorbed gases needs no elaborate argument in view of the well known occlusion of various gases by various metals,* of the general tendency of liquids to absorb gases and in view of the fact that standard writers like Geikie,† who do not attribute volcanic activity exclusively or mainly to this source, acknowledge the fact.

That these gases would tend to be given off in cooling and solidification ‡ would also be beyond doubt, unless it were true that they entered into combination more rapidly yet. Here is one of the two main doors for question. That the tendency to combine does not increase more rapidly than the tendency in solidifying to give off gases is indicated by the occurrence of uncombined water in volcanic glasses, by the giving off of steam and other vapors, by the occurrence of liquid enclosures in plutonic rocks, and, in general, by the fact that rocks must solidify at temperatures at which chemical affinities begin to weaken.

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* See Table 1. Also Dammer's Handbuch der Anorg. Chemie, vol. i, 1892. article "Okklusion."

† Text-book of Geology, 1893, pp. 10, 193, 265.

‡ But as a fluid tends to absorb gas in cooling, relief of pressure is needed to permit the escape of gas from a fluid. This is Reyer's position, I think.

At the same time it must be granted that there are signs of chemical combination going on in lavas. There are minerals like apatite which seem to have been formed gradually at various stages in or all through the development of the rock, from the very earliest time to the latest. Apatite is commonly classed among the earlier formed minerals, and rightly, but as it occurs in the cavities of the lava Capo di Bove or in the interstices of quartz-diabases it might be almost ranked as secondary. Michel-Lévy * also has referred to the spinels and magnetite as formed by chemical precipitation. The precipitating agent may well be conceived to be occluded oxygen gradually exerting its affinity on basic salts or metals or replacing fluorides. These actions do not seem to be very important, however, in view of the reasons stated in the preceding paragraph, more especially the elevated temperatures at which the tendency to lose gas would come into play.

It might be supposed, however, that these gases had already escaped and now formed the air and water surrounding our globe. Professor Shaler,† for example, is one of those who have suggested that lunar volcanoes were formed by escaping gases originally absorbed, while he does not look to the same cause for our earthly ones. The only way, however, one can imagine them to have escaped is by a solidification from the center, which gradually drove them out; ‡ but even if so, the pressure must have been enormous at the center, so that, as shown in Graham's experiments, in which the absorbed gases were given off only after being subjected some time to the air pump, much gas must have been occluded in the solid mass. Similarly the waters of the depths of the sea contain under their great pressure more gas than the surface waters; hence there is no need of imagining with Daubrée that the water or gas has percolated in from the outside. Doubtless it would do so had not the same forces which would draw it in now, kept it in from the beginning.

*Their Nature.*—The question naturally arises: What are these gases? We might find suggestions as to their nature from the atmosphere; from the gases given off by the iron and slag of a blast furnace, or from the gases found in meteorites. Some analyses of such gases we group in Table 1. More direct evidence we obtain from the gases and fluids found in the enclosures,§ in minerals of the plutonic rocks, and in the gases actually observed to escape from volcanoes or found in volcanic glasses.|| Finally we may obtain some hints from the new minerals of contact-

* Les Roches Eruptives, 1889, p. 37.

† Aspects of the Earth, p. 90.

‡ Undeutsch, Neues Jahrbuch, 1893, vol. ii, p. 320.

§ Geikie: Text-book of Geology, 1893, p. 111.

|| Op. cit., p. 193, and Iddings; Am. Jour. Geology, vol. 1, p. 168.

zones and the alteration of enclosed fragments.* These six lines of evidence agree remarkably well, and point to compounds of hydrogen, nitrogen, oxygen and carbon, probably variously associated according to temperature and pressure as principals. Sulphur (sulphates of the alkalis, $H_2S$, et cetera) and chlorides, fluorides and boric salts seem also to be important. At lower temperatures, instead of free hydrogen and carbonic oxide, we seem to have steam and carbonic acid.

TABLE I.—*Analyses of occluded Gases.*

| Analyses. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|---|---|---|---|---|---|---|---|---|---|
| H. . . . . . . . . . . . . . . | 88.8 | 77.0 | 67.8 | 83.3 | 35.0 | 21.0 | 85.68 | 38.98 | 41.44 |
| N. . . . . . . . . . . . . . . | 10.5 | 22.9 | 30.8 | 14.2 | 7.0 | 21.0 | 9.86 | 25.94 | 13.91 |
| CO. . . . . . . . . . . . . | 0.7 | . . . . . . | 2.2 | 2.5 | 50.3 | 58. | . . . . . . . | 28.80 | 29.77 |
| $CO_2$. . . . . . . . . . . . . | . . . . . . | . . . . . . | . . . . . . | . . . . . . | 7.7 | 0. | . . . . . . . | †6.28 | †14.88 |
| Sum . . . . . . . | 100.0 | 99.9 | 100.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Ratio of volume of gas to that of absorbent . . . . . . . . | $\frac{60}{100}$ | $\frac{45}{100}$ | $\frac{25}{100}$ | $\frac{35}{100}$ | $\frac{263}{100}$ | | $\frac{287}{100}$ | | |

1. Gas from Bessemer steel before adding spiegel. F. C. G. Müller: Iron, vol. xiii, 1879, p. 649.
2. " " " " after " " " " " " " "
3. " " open-hearth steel, " " " " " "
4. " " cupola pig-iron, " " " " " "
5. " " horseshoe nails heated two hours *in vacuo*. Graham: Proc. Royal Soc., June 20, 1866.
6. " " the same after heating two hours more. "
7. " " meteoric iron of Lenorto. "
8. " " cinder. Bell: Manufacture of Iron and Steel, p. 173.
9. " " "

*Importance in Crystallization of plutonic Rocks.*—Facts as to the importance of the part these gases play in the development of the plutonic rocks have accumulated so rapidly lately that one hardly knows where to begin or to stop. For one line of facts look at the minerals‡ such as hornblende, quartz, orthoclase and mica, which have been reproduced mainly or only with the assistance of superheated water or a similar medium. These minerals, which are the common constituents of plutonic rocks, rarely if ever occur in volcanic rocks, except under circumstances that point to their being either earlier than the eruption or of

* Geikie: Text-book of Geology, 1893, p. 606; Lacroix: Neues Jahrbuch, 1892, vol. i, p. 67.

† With $SO_2$, etc.

‡ For artificial minerals see Fouqué and Lévy, "Synthese des Mineraux, 1882, and that department in the Neues Jahrbuch.

secondary origin. Rosenbusch, in his "Microscopic Physiography of the Massive Rocks" and in his polemic with Michel-Lévy, has often referred to the importance of water as a mineralizer.

Iddings* has brought forward very clearly the possibility of rocks of very similar chemical composition having widely different mineral composition, and expressly assigns mineralizing agents as one cause of the difference. If I understand him and Dr Wadsworth also correctly, they seem to rank rate of cooling, so far as primary textures are concerned, as more important than the mineralizers. That rate of cooling is most important in determining the size of grain we shall all agree, but not so as to the replacement of minerals by others, except in the case of replacement by glass. I have been recently much struck, in studying certain massive flows of mottled melaphyre on Isle Royale, with the gradual increase in coarseness of the mottling, which is due to the increase in size of the patches of augite which enclose the felspar laths as we pass from the margin; but, besides these evidences of slower rate of cooling, we find to a large degree independently, in thin intrusive sheets, or in spots or in streaks, a very different texture—a more distinctly plutonic gabbro texture. This suggests another line of facts in the textures in the production of which minerals have been essential. The writings of Brögger, Rosenbusch, Irving, Romberg† and others on micropegmatite and pegmatite, and of Cross and Iddings, Rutley and others on spherulites, are full of hints in this direction. The miarolitic and panidiomorphic textures are other textures characteristic of the presence of mineralizers. On the other hand, the glassy, hyalopilitic, vesicular and amygdaloidal textures are characteristic of the escape of mineralizers. Iddings, however, argues that as these mineralizers are present in all magmas the differences in textures and mineral composition are to be credited rather to the other geologic conditions than to them. But what if the other conditions are those which permit the rapid escape of the mineralizers or retain them practically throughout crystallization? Would it then be an abuse of language to say that the mineralizers were an essential factor in separation of volcanic and plutonic rocks? The diverse character of the contact-zones, which will be discussed a little later, also points to the escape of the mineralizers as the important distinctive character of volcanic from plutonic rocks.

### Deep-seated Cracking.

*Its mental Conception difficult.*—We pass now to the second suggestion, to my mind by far the most shaky portion of the fabric. Can cracks ex-

* An. Rep. U. S. Geol. Survey, 1891, p. 657; also Proc. Phil. Soc. Washington, 1890, p. 213.

† Neues Jahrbuch, 1892; Beilage Band, vol. viii, p. 306.

tend far enough down into the earth's crust to strike a depth where there are abundant absorbed gases, and where there is a strong tendency to give them off, without first striking a plastic or viscous, either solid or liquid, zone, through which a crack could no more go than through a stream of honey or the sand of an hour-glass?

There are experiments of great importance by Kick * which seem to answer in the negative. In seeking and finding with brilliant success definitions of brittleness and hardness more precise than usual, he found that a block of so brittle a substance as salt, which has, however, been lately shown to be much more plastic than quartz or glass, enclosed in a copper tube and subjected to a strong hydrostatic pressure by filling the tube with oil and then screwing in a stopple, could be pressed from 8.1 millimeters down to 5.3 millimeters in a hydraulic press without being cracked. Calcite behaved similarly when enclosed in steam.†

Now, practically all rocks will be crushed by a pressure of 2,000 kilos per square centimeter, a pressure reached at 8,000 meters or five miles beneath the surface of the earth.

Below this, therefore, rocks might be expected to be highly plastic, and even above this they might perhaps be softened by superheated water, although if this water were already charged up to its capacity with mineral matter, its weakening effect may not be what some have thought. At any rate, long before we reach the region of anything like the heat of many lavas, or have more than barely come to a depth where the shrinkage through loss of heat tends to be more than the radical contraction, we shall have reached a plastic zone.

*Direct Evidence as to its Occurrence.*—This is certainly a serious difficulty, yet I think not fatal, and before trying to show the possibility of cracking far down into the earth, it is well to remember that, whether we can explain it or not, there are good reasons entirely, independent of this theory, to believe that it does so break.

In the first place, the depth of origin of earthquake shocks, which are generally accepted to be due to some kind of a break (in fact, can hardly be otherwise), have been estimated by noting the angle of emergence and circle of maximum throw,‡ by estimating the index circle of most rapid decrease in intensity of effect,§ and by comparing the times of arrival at different points.|| By these methods we find that the source of earth-

* Dingler's Polytechnic Journal, 1889, p. 448; abstracted in Scientific American.

† It seems quite possible that the enclosing fluid may have been solidified by pressure in Kick's experiment.

‡ Mallet discredited. See Geikie: Text-book of Geology, 1893, pp. 276, 279; and Schmidt, Neues Jahrbuch, 1893, vol. i, p. 55, and vol. ii, p. 44.

§ Dutton's Report on Charleston Earthquake: U. S. Geol. Survey, 1888, p. 313; Geikie: Op. cit., pp. 272 and 279.

|| v. Seebach: Das Mitteldeutsche Erdbeben, von 6 Märtz 1872, 1873.

quakes lies in the supposably plastic zone; often in fact just where we might expect, below the level of no strain; that is, where lateral compresson ceases and radial contraction and lateral tension due to cooling become dominant. Moreover, the common type of fault, the so-called normal fault, cannot be explained by compression, but, as McGee* has suggested and shown, may be due to difference of radial contraction, in which case, of course, the crust cannot rest on a layer sufficiently viscous or plastic to be unable to transmit and accumulate stresses so produced; and really when we look at the throw of the larger faults, like those of the great basin, it does seem natural that the crack should have extended even more than five miles down.†

So also, I presume, by similar methods to those applied to earthquakes, the roots of volcanoes have been assigned to a depth not over thirty miles; ‡ and, finally, it may be remarked that whenever or wherever the brecciated structure of obsidians and porphyries was formed the rock was then and there very capable of breaking.

*Its Possibility a priori.*—Now, when we come to consider theoretically the material properties of the earth as a whole, we find that in its astronomic relations, that is, in its precession and mutation and in its resistance to tidal deformation, it is rigid. Some geologists have been inclined to reject the work of the mathematicians as involving too many hypotheses; but it must be remembered that a wide range to the assumptions has been given, and that mathematics never deals with real things, but yet has proved a great help in interpreting them.

The rigidity spoken of refers to stresses which change in direction every moment and accomplish a cycle every twenty-four hours. They therefore throw very little light on its plasticity and viscosity with reference to stresses of slower application; that is, solidity or capacity for accumulating strain. The upholding of the great continental irregularities points at least to a high degree of viscosity, even though that might, if absolutely necessary, be otherwise explained through differences in density, et cetera.

Barus' experiments demonstrating that diabase solidifies under pressure § tend to show that it is solid; and all others which imply an accumulation of differences in radial contraction also suggest a solid earth; yet it may be plastic, for matter may be said to be perfectly plastic if, when flowage is started by exposure to a strain greater than it can stand, it will continue to flow, if free to do so in the direction of strain, so long as the strain is maintained ever so little above its elastic limit. At the

* Am. Jour. Sci., vol. xxvi, p. 294.
† Geikie: Op. cit., 1893, p. 552.
‡ Geikie: Op. cit., 1893, p. 267.
§ Am. Jour. Sci., vol. 46, 1893, p. 140.

same time that elastic limit may be high. Now consider for a moment what happens when a rock is crushed. Its elastic limit is passed and it begins to flow as a plastic body. Then tensile strains are produced and the stresses which these excite in consequence of its rigidity are soon too much for its ultimate strength or cohesiveness and it flies in pieces. If we return to Kick's experiments, we find that the brittle object experimented on is subjected under hydrostatic pressure to the stresses exerted by the surrounding viscous medium. Now it has been proved* that tensile shears, united with hydrostatic pressure greater than any one of them, combine or reduce to mere pressure. The body is therefore under pressure pure and simple, so that no cracks can be formed. It would seem at first sight as if the substrata of the earth were in the same condition, for certainly the pressure would increase within ten miles of depth far beyond anything that Kick used or that the rocks at the surface stand.

We must remember, however, that we are dealing with hydrostatic pressure, and not the vertical pressure of rocks, which would offer no direct resistance to lateral tension; therefore it is merely the weight of a column of water that we have to consider. This, at a depth of 16,000 to 21,000 meters, would have a pressure equal to that required to crush any rock. Above this point cracking is therefore theoretically possible, and before we reach this depth we should have passed the critical point of water and be dealing not with a liquid, but with a gas. The rocks would, if we could see them, be already beginning to glow with a dull, red heat; but as many lavas come to us much hotter than this we are not satisfied with the possibility of cracks only thus far. The probability of deeper cracking depends on the greatness of lateral shears, and whether intermolecular absorbed gaseous matter would convey the hydrostatic pressure.

As to the last point, I think we can see a very material difference between the pressure of water from without, aiding cohesiveness, and the pressure exerted by interpenetrating gas anxious to escape. Consider two points on each side of a surface where rupture is nearly ready to take place. It will take place when the cohesive force is not able to resist those tending to separate them. Now, the effect of the absorbed gas is to work against cohesion. It is precisely the opposite of hydrostatic pressure and may be treated as taking it up and neutralizing it. The one tends to condense, the other to expand.

*Its Production by Stresses.*—As to the tensile stresses produced we have, first, those due to cooling and contraction. As these are generated slowly, if the earth substance were a viscous fluid they would be yielded to by

* Becker: Bull. Geol. Soc. Am., vol. 4, p. 13.

viscous flow and would not be allowed to accumulate; and even if solid but viscous, they might not accumulate to any great extent; still, they would be of importance as producing a mild state of tension and slow flow upon which a quickly added stress can more effectively act; but if the great continental elevations are due to unequal cooling, the cold sea bottoms cooling fastest,* there must be considerable power of accumulation of stress.

The stress differences due to mountainous and continental elevations, which Darwin finds † are from 500 to 600 kilos per square centimeter above those which granite can stand. Their steady application would doubtless be productive of flow, but if owing to the contraction just spoken of the upper compressed crust were left for awhile partly self-supporting and then broke, coming down with sudden stress on the earth below,‡ there would be a strong tendency for the crack to extend down farther.

Finally we have the tidal stresses, of comparatively rapid application. The resistance of the earth to them points to its ability to resist, for times measured by fractions of a day, very large tangential stresses.§

I think that we may conclude, then, that the earth may crack for an indefinite distance down, some ways beyond the depth at which empty caves would become impossible.

*Explanatory of volcanic Phenomena.*—If this be granted, then the escape of gas from such cracks || would admirably explain volcanic action. The enormous escape of gas at the outset,¶ the eruption beginning with ashes, which are followed by lava later; the known connection of volcanoes with great fissure lines; their general occurrence on the margin of continents,** where special internal tangential stresses must be produced, are all quite natural. Such an origin would also make clear some things hard to explain in any other way, as, for instance, the apparent indifference, spoken of by Dutton, as to whether a volcanic eruption occurs on valley or crest. So, too, on the idea that the lava is brought up by the gas from a solid earth, it is easy to see why the lava should stand at different levels in adjacent vents; also, a change of barometric pressure would naturally effect the outflow of gas, and hence influence the activity.†† Finally, it is easy to see that in the case of a long-continued

* Faye: Comptes Rendus, August 19, 1889.

† Thomson and Tait: Natural Philosophy, p. 425.

‡ I do not mean that there is any cavity formed between them, but a temporary relief of compression such as is indicated by the less density of rocks under continents. See Preston: Am. Jour. Sci., vol. xxxiv, 1888, p. 305. Faye: Comptes Rendus, 1886, vol. cii, pp. 627, 1222.

§ Becker: Am. Jour. Sci., vol. 46, 1893, p. 139.

|| There is a little difference in the working of a siphon of soda water and champagne.

¶ Geikie: Op. cit., p. 193.

** Geikie: Op. cit., pp. 206, 259.

†† Geikie: Op. cit., p. 205.

eruption, after the first rush of gas the volcano must be fed by a viscous flow of the solid or liquid walls and the eruption must be more quiet and attended with more lava. The rock might be liquefied* in one of several ways. Relief of pressure might liquefy it; hotter gases from below might assist; chemical combinations, oxidation, etcetera, may raise or hinder the fall of the temperature, and, finally, viscous motion itself, like friction, tends to raise the temperature and increase liquidity. On the other hand, the escape and expansion of the gas would tend to lower the temperature.

## Igneous Phenomena and Causes.

*Increasing Heat and Basicity toward Earth's Center.*—That the earth's heat increases inward will be readily accepted, in view of the fact that everywhere when boring into it we find the temperature rises;† that all material from within is hot; and, according to astronomic data, it is a globe cooling from a not incalculable past.‡

That it passes gradually from a silicious rind to a core of iron may not be so easily granted, yet there is much to be said favoring it, and I know of nothing against it. Such would be the natural arrangement in a cooling globe composed of such elements. The specific weight of the earth is greater than that of the rocks at the surface, as it should be, and about in the right proportion.§ Absorbed gases, however, might reduce the specific weight of the center. Fragments of meteorites from space are often largely iron, and also often show a strong resemblance to the more basic rocks of the globe. The relation of the meteoric irons to the most basic earthy rocks is also indicated by many other things, as, for example, the troilite of one and pyrrhotite of the other, and the association of nickel.|| Small masses of pure iron have been found in basic terrestrial rocks. Iron is one of the abundant and widely diffused elements of the earth's crust, and the quantity of it in the igneous rocks increases as the amount of silica decreases.

The fact that in a general way rocks can be arranged in a series from acid to basic is well known and has been given a definite expression by Durocher and for the Iceland rocks by Bunsen. If, then, we could prove that the basic lavas are from a deeper source than the acid, the induction would be very strong. That this is the case is indicated by their greater weight and heat. I cannot find it anywhere stated on direct observa-

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*Some so-called volcanic bombs may be unliquefied fragments.

†Geikie: Op. cit., p. 49; Neues Jahrbuch, vol. 2, 1890, p. 234, and vol. 2, 1892, p. 39.

‡Geikie: Op. cit., p. 58; Walcott: Am. Jour. Geology, no. 7, 1893, p. 639.

§Geikie: Op. cit., p. 48; de Lapparent: Comptes Rendus, February 19, 1889, p. 369.

||Kosman: Neues Jahrbuch, vol. i, 1892, p. 83.

tion that the basic lavas are hotter than the acid,* though Dutton talks of their superfusion, and though there are numerous indirect indications that this is the case. Therefore I would suggest direct measurements of the temperature of acid lavas as a fruitful field for inquiry. While we often hear of white-hot basic lavas, I have never heard of white-hot acid lavas. They are more viscid,† although this may be due to the different chemical character. Then again I do not know, nor have I found records of rhyolites baking adjacent rocks, as basalts sometimes do. Acid rocks also are said to have less effect on enclosed fragments than basic ones have.‡ Then again the fluid enclosures, et cetera, in granite point to no very high temperature. I think that this cannot so truly be said of the certainly primary enclosures in basic eruptives. It is, of course, to be remembered that it is very unsafe to argue from the temperature at which lava is emitted as to its initial heat. Finally, the less oxidation of the iron in the basic and plutonic rocks, as evinced in the prevalence of magnetite over hematite, of green colors over red, and of hypersthene and olivine over biotite, et cetera,§ and directly in the analyses collected by Iddings,‖ is a very strong argument for the relation suggested. In other words, we know that rocks grow heavier and hotter toward the center of the earth, and in rocks furnished by volcanoes we find increasing weight associated with signs of increasing heat and with increasing amount and decreasing oxidation of iron. Continue this process and we must come to a core in which unoxidized iron is a prominent factor.

*Chemical Complexity of igneous Rock Series.*—Suppose now that this theory of igneous phenomena be accepted, what further deductions can we draw from it, and how far can they be verified? In the first place, we see that the material fed into the volcanic funnel will be at first from more than one level. Thus the series from acid to basic rocks will not be a simple one,¶ since a magma of a given silica percentage may be produced either by a mixture from a wide range of depth or by matter from more nearly one depth; yet one can see that there would be certain limits to the variation thus produced. Moreover, the cracks might cross, within the region of feeding, the lines of old intrusions or eruptions, and thus other variations be produced. This mixture of rocks from different levels might result in heating due to chemical reactions and would certainly tend to produce a corrosive effect. That the intra-

*Geikie: Op. cit., p. 222.

†Geikie: Op. cit., p. 247.

‡Lacroix: Neues Jahrbuch, vol. i, 1892, p. 67.

§de Lapparent: Comptes Rendus, February 18, 1889, p. 369.

‖U. S. Geol. Survey, Annual Report, 1891, pp. 629–649; see also Ransome: Bull. Department of Geol. University of California, vol. i, 1893, p. 106.

¶Rosenbusch: T. M. P. M., vol. xi, 1890, p. 144. See also Neues Jahrbuch vol. i, 1891, p. 61, and vol. 2, 1891, p. 56.

telluric phenocrysts are corroded is a well known fact, and that acid and basic quartz and olivine are alike corroded seems to point to some such neutralization of the magma. The presence of the quartz in quartz-basalt can readily be explained, and thus some of the so-called basic secretions and volcanic bombs may be due merely to imperfect mixture. Richthofen's law,* that lavas of medium basicity first appear, would find its basis in the obvious fact that the material first delivered would be of a mixed character if the crack were suddenly opened. I would not, however, deny the coöperation of liquation and splitting in producing varieties of magmas.

*Source and Diminution of acid Eruptives.*—The next point, the shallow origin of exclusively acid eruptions, has already been discussed in connection with the correlation of basicity and heat; but it is significant that we have no olivine-porphyries corresponding to quartz-basalts. The laccolitic form, so common in acid rocks, may also point to a less degree of energy than the enormous outbursts of basalt. It does not seem as if there were ever, certainly not in later times, so extensive overflows of rhyolites as of basalts, and this would be a necessary consequence if the acid is a superficial layer, with less gas to give off than the layers below, and continually growing cooler and stiffer.

The effect and indications of higher temperature in basic rocks have already been discussed. Is the frequent greater size of the vesicles in basic lavas connected with relief from a greater pressure?

## Contact Zones.

*Intrusive Rocks.*—So far we have treated mainly of volcanic discharge of gases. Let us now look at their behavior in cases of intrusion. If there is a crack or line of weakness not leading to the surface, the gases will first escape into it, and then, if it is relatively cooler, decrease in pressure, so that the magma from below will force in after them; but it will not be able to fill the space entirely unless the gases are able to escape into the walls of the cavity. Thus there may be a gradual settling of the rock into place, producing the "protoclastic," "Mortel" and similar textures.† If the lava be quite viscous and the cavity a narrow fissure, it may leave a vacant place. This summer I saw such a place near the head of McCargoes cove on Isle Royale. In this case a little intruded dike was continued by a vein of comby quartz.

Beside the forerunning gases we have those of the magma itself to account for, which may be done in three ways. One way is to suppose that they too pass into the wall rock. Then we have that characteristic

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* Geikie: Op. cit., pp. 262, 263.

† Brögger: Zeits. fur Kr. 1890, p. 105. Adams: Neues Jahrbuch, Beilage Band, viii, 1893, p. 459.

feature of the plutonic rocks, the contact-zone. This explains well why they occur alike around granite and gabbro* and produce no marked chemical alteration, as Harker and Wadsworth have observed. A little fluorization may sometimes be noted. On the other hand, I find no record of contact action of porphyries. They have neither the heat nor the water. The basaltic rocks show almost purely the action of heat at their baked, indurated and semi-fused contacts, and better than in any other way the heterogeneity of the rocks which have been called diabases is shown by the variety of contact-zones reported. On the strength of these alone I should expel some to the melaphyre-basalt family, class some with the gabbros, regardless of diallagic cleavage, and maintain the name for a distinct group occurring characteristically in dikes and intrusive sheets.

*Textures of Rocks.*—These gases may also remain in the magma throughout crystallization. In such cases there will be interstices left, giving us the miarolitic texture, with which the panidiomorphic textures are closely akin. In the last stages of cooling, when there are but small residual spaces left, they would doubtless be filled with mineralized water. The crystallization thereafter belongs to what Brögger has called the pneumatolytic stage, and microline, muscovite, calcite and quartz are some of the probable products. What I have described as the acid interstices in quartz-diabases, which in their intergrowths of quartz and felspar in association with hornblende and biotite remind one at once of acid rocks, seem to have been thus found. Lawson has described similar things from the north shore of Lake Superior. He moreover added the important observation that they increase and the rock becomes more acid toward the center of the dike. This leads naturally to the third disposition of the gases that can be thought of; that is, that they may be concentrated into fissures and cavities in the rock. The case of the coarse mottled melaphyres of Isle Royale, with the streaks here and there of a more gabbroid texture, shows the beginning of this process.

Any one who has studied a granite area in the field must, I think, have been struck with the difficulty of separating segregation veins from pegmatites on the one hand, and pegmatites from the normal granite on the other.† Very significant in this connection is the change in position of Professor Rosenbusch, who used to class pegmatites with veins, but now places them with igneous rocks. Such an authority must have had good reasons both for the position he formerly had and that which he now takes. The explanation is simple. The pegmatites are one form of residual magmas, the segregation veins a farther step. Brögger's work

* Bayley has described a case of the latter at Pigeon point. Am. Jour. Sci., vol, xxxix, 1890, p. 273.
† Geikie : Op. cit., p. 700.

on the rocks of southern Norway contains a mass of facts bearing in this direction, and his pneumatolytic theory is directly in line with our argument. The relation of pegmatites and micropegmatite is close, and I believe both to be formed from water-charged magmas.

I have a specimen in which a quartz-felspar vein is backed by and gradually passes into a beautifully developed graphic granite. The micropegmatite or granophyric texture has in many cases been shown to be secondary, by Bayley, Williams, Irving, and Romberg, and is considered to be always so by Wadswarth. We must either give it up as a primary texture entirely or class it in the last pneumatolytic stage.

*Formation of Veins.*—I do not care to dwell on the subject of veins, but would merely call attention to the fact that in the recognition of the importance of these exuding gases the theory of filling by ascent would have a powerful support. It has been remarked that we have an almost continuous series from volcanoes to hot springs. Why should we not have an almost continuous series of rocks? So, too, certain kinds of ores are genetically connected with certain rocks, as tin with granites, and nickel and mercury (cinnabar) with serpentines, which is readily accounted for by supposing the veins to be charged with the condensed gases from them.

## Magmatic Zones.

*Relation of Depth and increasing Pressure and Temperature.*—We have generally talked of gas, but it is obvious that the actual temperature and pressure may at times make them liquid. It must be remembered, however, that above a certain temperature no amount of pressure will liquefy a gas, although the gas may occupy no more space than the fluid. Thus temperature is on the whole the most important factor, pressure but serving somewhat to neutralize it. When we come to chemical reactions, however, the effect of pressure may be more considerable; but this is not yet determined. With the rapid strides that theoretical chemistry is making, in the hands of Barus and others, we may soon hope to know. Then from studies of blast-furnace reactions we may advance our knowledge of the earth's interior, for it is obvious, according to the theory here outlined, that the likeness of volcanic action to that of a blast furnace is striking. In both we have iron at the bottom, above a reducing and basic zone and yet above an oxidized zone. Similarly the temperature decreases going upward, and similar gases are absorbed or in chemical activity.

I have therefore prepared Table II, showing the increasing pressure and increasing temperature, relative to the depth from the earth's surface. By the side of the pressure column I have placed the crushing

TABLE II.—*Relation of Depth and increasing Pressure and Temperature.*

| Depth from surface. | | | Superincumbent weight of a column of sp. gr. 2.7 (kilos per sq. cm. = 14.221 lbs. per sq. in.) | Pressure data; 1 atmosphere = 1.033 kilos per sq. cm. | Depths of earthquakes—meters. | Magmatic zones. | Temperatures of a gradient of 3° C. in 100 m., 1° F. in 60 feet. | Blast-furnace reactions) Bell). | Important temperatures; artificial formation of minerals. |
|---|---|---|---|---|---|---|---|---|---|
| Feet = 0.3048 m. | Miles = 1.6093 k. | Kilometers. | | | | | | | |
| | 1 | 1 | 270 | 201.1, critical pressure of water. | 100, Swabian Alps earthquake. | | 30 | ........ | 30.92, critical T for $CO_2$. |
| | | 2 | 540 | | | | 60 | | |
| 10,000 | 2 | 3 | 810 | Level of no strain (Fisher). | | | 90 | ........ | 100, boiling point, $H_2O$. |
| | | 4 | 1,080 | 1,000, crushing of Fürstenstem granite. | | | 120 | 139, CO reacts on Fe. | |
| | 3 | 5 | 1,350 | | | | 150 | ........ | 150–180, apatite from phosphate of lime, and sodic chloride. |
| 20,000 | 4 | 6 | 1,620 | 1,600, crushing of granite, first quality. | 6,000, Switzerland, Jan. 7, 1889. | | 180 | 200, O faintly lost by $Fe_2O_3$. | |
| | | | | | | | 210 | 210, O decidedly lost. | |
| | | 7 | 1,890 | Level of no strain (Davidson). | | | 240 | ........ | 250, pyrrhotite formed from $FeCl_2$ and $H_2S$. |
| | 5 | 8 | 2,160 | Consolidation of granite, Ward. | | | 270 | | |
| | | 9 | 2,430 | 2,000, graywacke crushes. | | | 300 | | |
| 30,000 | 6 | 10 | 2,700 | 2,077, Auvergne basalt crushes. | 8,880, W. German. | | 330 | 338, top of blast furnace; coal distils; ore dehydrates; zone of reduction and carbon impregnation. | 340, nephelite formed. |
| | 7 | 11 | 2,970 | ROCK NOT FED INTO CRACK IN MASSES. | 9,275, Calabrian, 1827. | | 360 | | 370, critical T for $H_2O$. |
| | | 12 | 3,240 | | | | | | |
| 40,000 | 8 | 13 | 3,510 | ........ | 12,880, Charleston, S.C.; Dutton. | Acid. | | | |
| | 9 | 14 | 3,780 | ........ | 9,000 to 15,000, Naples and Ischia. | | 390 | 398, C takes O from $Fe_2O_3$. | |
| 50,000 | | 15 | 4,050 | Consolidation of granite, Sorby | | | 420 | 426, $CO_2$ acts upon Fe. | |
| | 10 | 16 | 4,320 | ........ | 10,000, Turkestan. | | 450 | 443, DULL RED HEAT ........ | Zone in which CO becomes C + CO in cooling. |
| | 11 | 17 | 4,590 | | | | 480 | Limestone decomposition; also reduction in blast furnace. | |
| 60,000 | | 18 | 4,860 | | 17,956, Germany, 1872; Charleston, S. C.; Dutton. | | 510 | | Muscovite formed. |
| | 12 | 19 | 5,130 | | | | 540 | | 500, nephelite, sodalite, orthoclase, anorthite. |
| 70,000 | 13 | 20 | 5,400 | | | | 570 | | |
| | | 21 | 5,670 | | | | 600 | | 570, artificial liparite. |
| | 14 | 22 | 5,940 | | | Intermediate. | 630 | 639, RED HOT. Steam + Fe = $Fe_2O_3$ + H. | 550, hornblende formed (Krustchoff). |
| 80,000 | 15 | 23 | 6,210 | | | | 660 | | |
| | | 24 | 6,480 | | | | 690 | | 639, biotite formed (Doelter). |
| | 16 | 25 | 6,750 | Hydrostatic pressure of column of pure water equal to crushing pressure of granite. | | | 720 | | 700, Vesuvius lava, 1855. |
| | | 26 | 7,020 | | 27,113, Herzogenrath, 1877. | | 750 | | |
| 90,000 | 17 | 27 | 7,290 | | 26,266, Sillen, 1858. | | 780 | | |
| | 18 | 28 | 7,560 | | | | 810 | 815, FULL RED HEAT. | |
| | | 29 | 7,830 | | | | 840 | $CO_2$ acts on C. | |
| 100,000 | 19 | 30 | 8,100 | | | Basic. | 870 | Phosphate of Fe loses F to Si; cast iron decomposes phosphate of lime. | |
| | | 31 | 8,370 | | | | 900 | | |
| | 20 | 32 | 8,640 | 8,579, limit of elastic pressure of steam. | | | 930 | | |
| | 21 | 33 | 8,910 | | | | 960 | | |
| | | 34 | 9,180 | | | | 990 | ........ | 1,000, enstatite fuses. |
| | 22 | 35 | 9,450 | | | | 1,020 | ........ | 1,016, silver fuses; Vesuvius lava, 1819. |
| | | 36 | 9,720 | | | | 1,050 | | |
| | 23 | 37 | 9,990 | | | | 1,080 | ........ | 1,095, diabase fuses (Barus). |
| | 24 | 38 | 10,260 | ........ | 38,806, Rhine, 1846. | | 1,110 | | |
| | | 39 | 10,530 | | | | 1,140 | | |
| | 25 | 40 | 10,800 | | Charleston, S.C., according to Schmidt, 107,500. | | 1,170 | 1,172, $CO_2$ dissociated........ | 1,204, white-hot lava; copper fuses; pig-iron fuses. |
| | | | | | | | 1,200 | | |
| | | | | | 55,000, Cachar, 1869. | | 1,230 | WHITE HEAT. | |
| | | | | | 56,000, Riobamba, 1797. | | | | 1,500, platinum fuses. |

strength of certain rocks, with the depth of some earthquakes and other pressure data of interest. By the side of the temperature column I have placed Bell's diagram of blast-furnace reactions,* with various other thermal data of interest.

From these we may, to make our conceptions definite, guess somewhat at the zone whence the different rocks are derived. I have avoided any calculations in this paper, first, because I thought the evidence could be just as well presented and be more interesting without them; second, the data are really too uncertain to give any closer results than can be got from qualitative methods; and, third, if I once got started in calculations I should need a whole bulletin.

*Probable Reactions of gas-making Elements.*—The behavior of a few elements first claims our attention. Oxygen at high temperatures largely or wholly dissociated steadily combines, at first with carbon to carbonic oxide at about 1200° centigrade, then perhaps with iron and silicon to ferrous iron, in such compounds as olivine, and then also magnetite, forming some carbon dioxide ($CO_2$). It would probably not attack the free hydrogen at all until the iron was all oxidized. About 400° centigrade is a peculiar point where the affinities of carbon monoxide (CO) for another atom of oxygen and those of iron or the same element are about balanced, and there is a tendency for carbon monoxide (CO) to divide into carbon and carbon dioxide ($CO_2$). Not far below this is the critical temperature of water, and about here any spare oxygen would combine with any free hydrogen. Very soon we shall be altogether in an oxidized rock and below the critical temperature of water, when the pressure would immediately convert steam into water.

At first the carbide of iron or graphite or diamond would gradually oxidize. Under certain circumstances hydrocarbons form. Nitrogen would be inert generally, but might form ammonia compounds. Probably sulphur early combines with iron in the troilite of the meteorites and pyrrhotite of the gabbros, and may turn to pyrite, but more likely becomes $H_2S$ or oxidized and furnish its $SO_3$ for hauynite, the solfataras, and escaping alkaline sulphates, so often found in volcanoes. It would thus set free much heat. Fluorine is probably most abundant in the acid zone as silico-fluorides, and chlorine more abundant in the basic zone.

The top of the acid zone will probably be about where the pressure is enough to crush any rock. There will occur at this level a sudden increase of pressure on the enclosed water, which very likely may produce decided changes in physical condition. About here also may be the level of no strain, where lateral compression ends—the starting place of many earthquakes. As granites often contain enclosures of carbon

* Iron and Steel, plate 6 et passim.

dioxide ($CO_2$), it certainly does not come from a temperature where that gas could not exist. White mica is also characteristic, and it is decomposed at a full-red heat. Hornblende, which is quite characteristic of the medium rocks, has been formed at 550° centigrade or a red heat; but at a not much higher temperature, in the presence of iron, steam is dissociated, and hornblende might be burnt brown. Here, then, may be the limit of the neutral magmas.

Below this we shall have the basic zone, containing not steam, but free hydrogen, and extending down to a white heat. This might require a depth of 40,000 meters, say, twenty-five miles, which is also about the limit of earthquake depths. Somewhere below this depth there would come a limit to the expansive power of gas to raise a column of lava,* and from below this level there could be no direct feeding, although of course the gases themselves might work out.

*Basis of Rock Classification.*—It is to be understood that these depths and zones are put in the table for the purpose of clarifying our conceptions, and that the theory is not to be burdened with a rigid interpretation of them. For example, we have entirely neglected pressure as influencing reactions, yet since Iddings has noted that the igneous rocks show little trace of the effect of pressure, pure and simple, possibly we may not be so far from the truth. Long ago it has been remarked that the three factors in the crystallization of a rock are the loss of pressure, temperature and of included gases, the last two being by far the most important. Let us employ symbols, as in the case of the three pinacoids of a crystal, to which shall be assigned the following values: $P =$ rate of loss of pressure; $M$ (minera lisers) = rate of loss of absorbed gas; $T =$ rate of loss of heat. Then the coarseness of a texture will increase with the slowness of the loss, the kind of texture with the relative rate of loss. $T$ less than $M$ will be characteristic of the glassy textures and volcanic rocks, rocks potentially amygdaloidal, and $T$ greater than $M$ of the dike rocks in general, the pegmatites and veins. The plutonic rocks will generally have $T$ equal or, rather, concomitant with $M$. If we use the sign = to indicate concomitant variation and > to indicate more rapid loss, we may classify the rocks as follows:

| | | |
|---|---|---|
| Abyssal, | $M = T = P$. | Crust of the earth, fundamental or batholitic gneiss (?), allotriomorphic texture (?). |
| | $> P$. | Hypidiomorphic and cement textures. |
| | $< P$. | Miarolitic texture. |
| Intrusives, | $M < T = P$. | Veins filled by ascent. |
| | $< P$. | Panidiomorphic dikes. |
| | $> P$. | Pegmatites. |

* But it should be remembered that the weight to be lifted is of a column of foaming lava full of gas.

Volcanics, $M > T = P$. That is, $P$ and $M$ are greater, more rapid than $T$, ordinary effusives.
$> P$. Some marginal forms of plutonics.

The above suggestions show how a classification of rocks on other than a chemical basis might be carried out. It might be extended a great deal farther. Thus the difference between obsidians and pitchstones is that in one $M > T$, in the other $M < T$. Personally, however, I should prefer a classification based neither on mode of occurrence nor origin, but on the textures, those textures being chosen, however, which are most significant.

## Other possible Activities of Absorbed Gases.

As the previous points have mainly engaged my thought, I should prefer to stop here, but it would be unfair not to notice the fact that escaping gas might have activities other than those already noticed. Oozing up by a slow exudation, they might be supposed to produce a general contact-zone corresponding to limited contact-zones around local abyssal masses. They might produce mutual interaction between alternation beds of different character, but there are very limited traces of this sort of action. So, too, the crystalline schists have often a striking mineralogic parallelism with contact-zone rocks. They might help in charging many mineral waters where we do not suspect them, as, for example, the carbonated waters of the Eifel. If they oozed up as a cooling water they would be charged with and deposit silica, and the silification of sandstones into quartzites without crushing, which Van Hise* mentions, may have their help.

Wadsworth ascribes many minerals and textures usually considered primary to the action of percolating waters after consolidation. If he is right, then these exuding waters probably play a greater rôle than I suppose.

It is also to be noted that, as Le Conte has remarked,† there would be a continuous abstracting of material from below and adding it to the surface. In a region much cut by dikes I once estimated the area covered by them at six per cent.

Finally, we see that in all these ways escaping gases would accelerate the flow of energy from the earth's interior. They might assist very greatly in promoting unequal cooling, and hence unradial contraction; and by thus abstracting heat a few miles down and adding it to the upper layers, both directly and indirectly they might, by accelerating crushing, alter the thermal gradient appreciably. It is evident their

* Bull. U. S. Geol. Survey, no. 8.
† Am. Jour. Geology, 1893, p. 564.

total effect would be to accelerate cooling and to lower the rate of increase observed after a certain time from what it would otherwise be, and thus cause an overestimate of the time of cooling, if it were computed from a given rate of increase noticed at the surface without allowing for them.

### Suggested Lines of Inquiry.

As no theory is worth much which does not suggest inquiry, I would in conclusion point out some of the promising lines of research opened up.

The temperature and physical conditions of acid lavas are very imperfectly known.

The association of depth of earthquake shocks and character of lavas in volcanoes has not been studied.

There has been almost no study of the enclosures occurring in basic plutonics.

The contact-zones of porphyries have not been studied or their absence stated with sufficient definiteness.

The study of the oxidation of iron in reliably fresh rocks promises important results.

The further chemical examination of gases occluded in meteorites and volcanic glasses would be instructive in connection with the questions herein discussed.

## *COMMENTS.*

The foregoing is the paper as presented to the Society at the Boston meeting, but as public discussion, by reason of the crowded program, was not possible on that occasion, I desire to add a few words chiefly in report of private remarks made by members who were present at the reading of the paper and one of whom, at least, had expressed a desire to be heard concerning it.

Mr Darton called my attention to the interesting fact that Professor William Libbey, Junior, of Princeton, N. J., who made somewhat extended observations among the extinct and active volcanoes of the Hawaiian islands, had noticed gas lines in the spectra of glowing lavas—an excellent means of determining not only the presence of gases, but their composition as well.

Professor Kemp referred to an earthquake which occurred in the western United States and which is said to have had its source at a depth of more than fifty miles. He also called attention to the abundance of sulphur beds in volcanic regions as indicating the importance of that mineralizer.

Messrs Cross and Emmons confirmed from their wide experience the lack of noteworthy caustic phenomena in the contacts of rhyolites, but remarked that signs of caustic action are also often absent in basaltic contacts. They would not be expected to occur around partly cooled basalts.

Mr Cross also commented on the fact of observation that similar magmas, in the same area, were in some cases accompanied by, and in others free from, mineralizing agents. Thus the great laccolitic masses of porphyrite in the West Elk mountains, Colorado, were not accompanied by contact phenomena indicating the presence of gaseous mineralizers, while the diorite masses of the adjacent Elk mountains were surrounded by broad contact-zones, in which the development of scapolite, vesuvianite, garnet, pyroxene, specular hematite, and various other minerals attested to the presence of chlorine, fluorine, and perhaps other agents in the magma at eruption.

Professor Crosby's paper, "Origin of the Coarsely Crystalline Vein Granites on Pegmatites," which was also read at this meeting, in part overlaps mine in a confirmatory way.

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# EXTRAMORAINIC DRIFT BETWEEN THE DELAWARE AND THE SCHUYLKILL

BY EDWARD H. WILLIAMS, JUNIOR

(*Read before the Society December 29, 1893*)

CONTENTS



## Review of previous Investigations.

The part of Pennsylvania described in this paper was allotted in the recent state survey to Professor Frederick Prime, junior, and in 1874 he made his first report (D), on page 62 of which the state geologist notes that Professor Prime "has wisely said nothing in his report about his observations on supposed glacial drift." He further notes that Mr Chance found, in the spring of 1875, a moraine behind the Lehigh Gap. In Professor Prime's second report, DD, in 1878, he devotes chapter xxiv to "The Glacial Epoch," and states that his efforts to follow the lines of bowlders was "a hopeless one and had to be abandoned." He further notes the finding of vegetable remains in what must have been subglacial till, and characterizes the filling of a great range of limonite mines as "drift." In his third report, D 3, volume i, also of 1878, he seems to

have further discussed the subject; but the comment of the state geologist on page 37 is all that remains. He notes: "Professor Prime suggests in his report a possibility that the remarkable evenness of the limestone plain may be partly due to a drift deposit." This suggestion is qualified by the state geologist on the next page in the statement: "The drift deposit which helps to give a plain-like aspect to the limestone belt is not unstratified glacial moraine matter, but is a superficial bed of stratified sand and gravel distributed by and in water." The finding of a few flat pieces of syenite is proof to him that the deposits are local, and he dismisses the subject with the statement that the Bethlehem gravels are either a "high-flood river deposit, or else ancient high-level river-channel deposit;" attributes the latter to an old bed of the Lehigh which has cut a new channel through solid rock for 80 feet, and brushes aside Professor Prime's theory with the remark that the flatness of the limestone is not due to any kind of a supposed covering of local drift.

In 1882 Professor I. C. White discusses the "moraine" found by Mr Chance at Lehigh Gap (G6) as follows: "The ice undoubtedly passed as far west as the Lehigh river, because there we find the old channel of Aquanchicola creek choked up with drift, and the stream compelled to cut a new one around it to the south through the solid strata, before entering the Lehigh."

Of the recent findings in the region note will be made only of the location of a "pebbly terrace" at Lehighton, by Professor G. F. Wright,* 75 feet above the river.

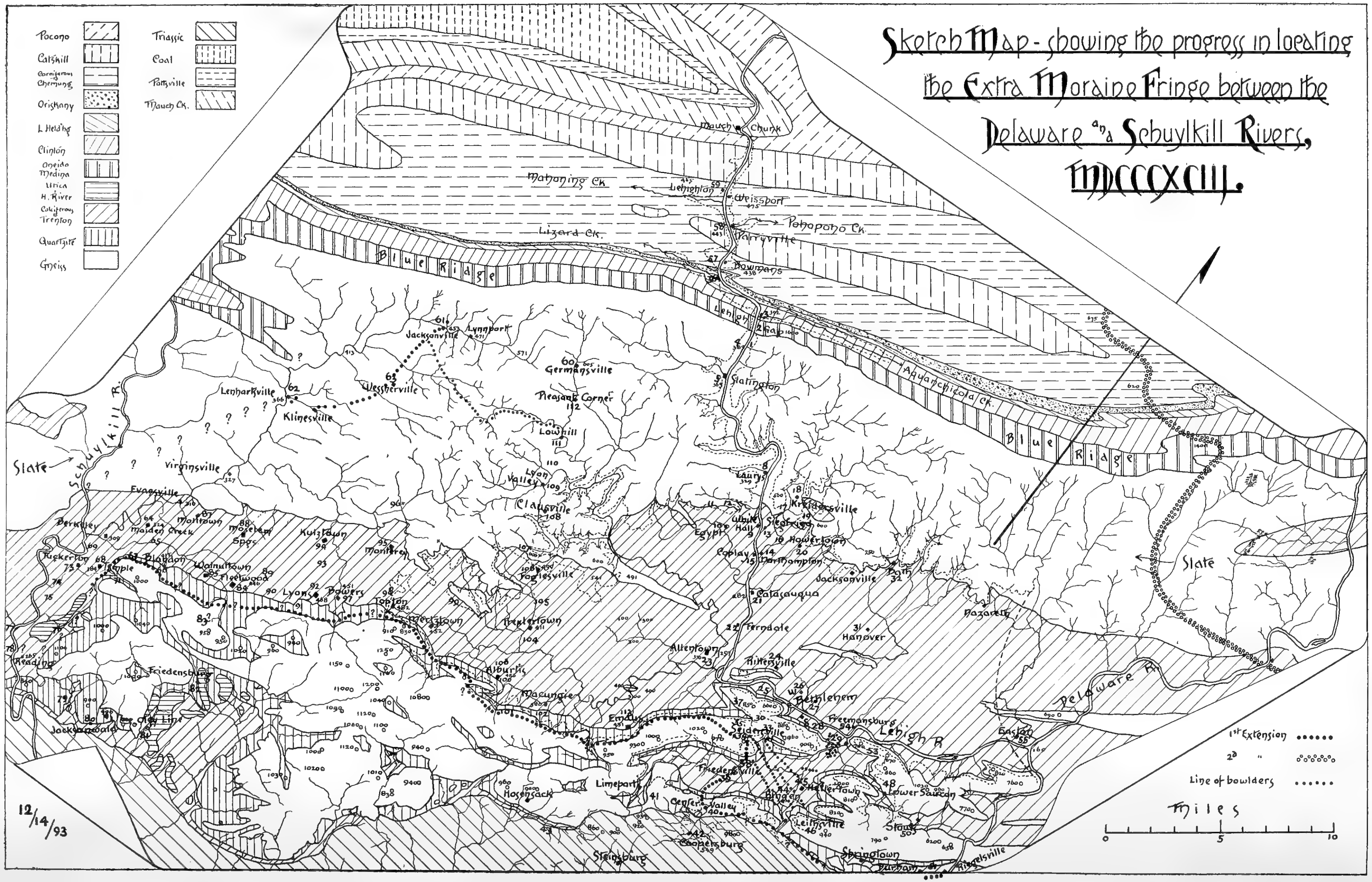
## Area Studied.

### *TOPOGRAPHIC FEATURES.*

The accompanying map, plate 9, shows the region examined during the past year of 1893.† Only that part south of the Blue ridge was studied with any attempt at thoroughness, owing to the limited time at my disposal. It is proposed to finish this portion during the coming year and to extend the work beyond the Ridge. Elevations are based on mean tide, and the points noted are indicated on the map by minute circles. The terminal moraine of Messrs Lewis and Wright is shown by double lines of open circles; the limits of the furthest ice invasion by the larger black dots, and the southern limit of the larger bowlders by the smaller ones. Interrogation points are placed where doubt exists as to the position of the two latter lines. The dotted line from Naza-

* Proc. Acad. Nat. Sci., Philadelphia, 1892, p. 476.

† My assistant was Mr Joseph Barrell, and I desire to make suitable acknowledgment of the valuable work done by him.


Sketch Map - showing the progress in locating the Extra Moraine Fringe between the Delaware and Schuylkill Rivers, MDCCCXCIII.
Pocono
Catskill
Corniferous Chemung
Oriskany
L. Held'bg
Clinton
Oneida Medina
Utica H. River
Calciferous Trenton
Quartzite
Gneiss
Triassic
Coal
Pottsville
Mauch Ck.
Mauch Chunk
Lehighton
Weissport
Parryville
Pohopoco Ck.
Mahoning Ck.
Lizard Ck.
Bowmans
Blue Ridge
Lehigh Gap
Aquanchicola Ck.
Slatington
Jacksonville
Lynnport
Germansville
Pleasant Corner
Lowhill
Lenharkville
Wessnerville
Klinesville
Virginsville
Lyon Valley
Claussville
Laurys
Kreidersville
Slate
Schuylkill R.
Evansville
Berkeley
Maiden Creek
Moselem Spgs.
Kutztown
Monterey
Walnuttown
Fleetwood
Lyons
Bowers
Topton
Mertztown
Trexlertown
Fogelsville
Egypt
White Hall
Siegfried
Howertown
Coplay
Northampton
Jacksonville
Bath
Catasauqua
Nazareth
Ferndale
Hanover
Allentown
Rittersville
Bethlehem
Freemansburg
Lehigh R.
Delaware R.
Easton
Tuckerton
Temple
Blandon
Reading
Friedensburg
Jacksonwald
Alburtis
Macungie
Emaus
Seidersville
Friedensville
Hellertown
Lower Saucon
Hosensack
Limeport
Center Valley
Leithsville
Stouts
Coopersburg
Springtown
Steinsburg
Durham
Riegelsville
1st Extension
2d "
Line of bowlders
Miles
0
5
10
12/14/93

reth westward along the slate belt to the Lehigh, with divergence north to Mauch Chunk and return, and an extension to a point north of Topton, and a return to Easton along the southern border of the limestone and around the Saucon valley, marks the 500-foot contour, and includes the lake formed by the damming of the waters of the Lehigh by the glacier. The legend on the map describes the various forms of cross-section of the deposits, but it must be noted that the broad slate belt is left clear to avoid confusion.

The height of the crest of the Blue ridge will average 1,500 feet, and the next ridge to the north reaches 800 feet, and is formed by the vertical outcrop of the Oriskany. Between the two the Aquanchicola flows westward to meet the Lehigh at the gap. The Ridge falls abruptly over the basset edges of the Oneida and Medina sandstones and conglomerates to the Hudson river slates at an average elevation of 750 feet. This slate belt is from seven to ten miles wide, and consists of a broken and hilly region, whose southern edge, where it meets the limestone plain, is at 500 feet. This plain is eight miles wide east of Trexlertown, and nearly four west of that place. East of Topton the northern edge of the limestone is 20 feet higher than the southern side, while west of that place the northern edge will average 80 feet lower than the opposite side. The Archean highlands are variously called the South mountains and the Durham and Reading hills. They are divided into two parts by the Saucon valley; that to the east is twelve miles long, and has but one elevation (the Hexenkopf) above 1,000 feet, while that to the west stretches to the Schuylkill at an average elevation of 800 feet, with forty peaks rising above 1,000 feet, and eleven above 1,100 feet. It has an average width of six miles, and is bordered, except on the extreme eastern end, by Cambrian quartzite, and generally capped by it in patches to the west.

### *RIVER SYSTEMS OF THE REGION.*

Between the Blue ridge and Riegelsville the Delaware falls from 298 feet to 124, while between the Ridge and Reading the Schuylkill descends from 402 feet to 195. The Lehigh enters the region shown by the map at Mauch Chunk, with an elevation of 504 feet, and flows thence to Allentown slightly north of a line bearing South 40° East between those places, and, in 29 miles, falls to 235 feet, or 9 feet per mile. At Allentown South mountain turns it sharply to north 70° east, and in that direction it flows to the Delaware at Easton at 160 feet, by a fall of 4.2 feet per mile, though the greater part of the distance has a fall of but 3 feet per mile, and it is only as it nears the Delaware that the slope of the bed becomes great. This must be remembered in connection with the discussion of postglacial erosion presented later.

South of the Ridge the Bushkill and the streams between it and the Delaware flow into the latter river, as do those in the Durham valley and in the small valley just north of it. In the great valley a divide from Topton to Germansville separates the waters of the Lehigh from those of the Schuylkill. The main affluents of the Lehigh are the Manokisy and Hokendauqua from the north, the Jordan and Little Lehigh from the west, and the Saucon from the south. Those of the Schuylkill are Maiden and Sacony creeks. The Durham and Saucon valleys are separated at Leithsville by a narrow divide in quartzites at 445 feet, and with slopes of 71 feet per mile eastward, and 114 feet per mile westward. Between the Saucon and the small valley north of the Durham there is a narrow divide in gneiss at Stouts, at 505 feet, with a sharp slope of 225 feet per mile on either side. There are other and higher divides that do not enter into the discussion of the Saucon valley.

In the main valley the Lehigh-Schuylkill divide has been noted at Topton. It is in limestone at 495 to 510 feet and does not vary 10 feet in two miles along its crest. The surface of the valley from the divide to Allentown varies little from a slope of 20 feet per mile for 14 miles, while to the west it falls 40 feet per mile for 3 miles to Sacony creek; thence to Kutztown it rises 119 feet per mile for three-fourths of a mile, and falls to the small creek to the west 71 feet per mile. From this place to Moselem Springs the rise is identical in grade and length with that from the Sacony to Kutztown; and from the Springs to the Schuylkill is a fall of 25 feet per mile for 7 miles. The Sacony and the small creek to the west both flow north to Maiden creek. Attention is called to the peculiar direction of this flow, as well as to the fact before noted, that the northern edge of the valley is 80 feet lower than the southern one. The Topton divide is therefore the only one of the three that is higher at the northern end. It is also worthy of notice that the streams east of the Topton divide flow south through the slate belt and east and west when they reach the limestone, while west of that divide the directions are reversed.

As all of the divides noted have been covered with drift, their elevations above tide at the close of glaciation may be relatively determined by the slope of their sides and the width of the valleys in which they occur. As those at Stouts and Leithsville are in narrow valleys with high and steep sides and their own sides slope 71 to 225 feet per mile, the rainfall from the extensive highlands would be concentrated on a small area, so that they must have been denuded much more than the wide divide at Topton, with its level and broad valley, where all the water that fell to the northward was diverted immediately westward, and only that from the southern highlands performed erosive work. When we consider

certain peculiarities in the distribution of the clay cap, we will conclude that the Topton divide must have been the lowest of the three at the close of glaciation.

### *ROCKS OF THE REGION.*

As these have been fully described in the state surveys, only a comparison of similar features of different formations will be attempted. The Archean rock is a granulite* varying to gneiss, generally syenitic. The quartzite is placed in the Potsdam by the state survey, and varies to a gritty sandstone eastward from Reading and is a red shale locally at South Bethlehem. Its lower part is dense arkose, and the localities where the measures are flexed are noted for breccias. The gritty varieties abound in *Scolithus linearis ;* are weathered to a whitish sand, and lose the conchoidal fracture of the quartzite. The pebbles of this formation of a recent origin can be generally told from the Paleozoic pebbles of the same (as found in the basal conglomerate of the Trias) by the reddish or purplish color of the latter, due to long immersion in ferruginous mud. This color extends from a few lines to an inch from the surface, while the interior is fresh. There are, however, Paleozoic pebbles which have escaped this staining, and such cannot be told from recent ones, and resemble, also, the rolled pieces of the lighter bands of the Oneida-Medina formation at the Blue ridge. When the latter conglomerate carries slate and chert pebbles there is a ready means of distinction. The Oneida sandstones have whitish streaks—they cannot be called veins—several inches in length that are not found in the Potsdam rock, but when they do not exist there is difficulty if not impossibility of distinction by the pocket lens, as both have a conchoidal fracture, a similar arrangement of grains and matrix, and a similar habit of weathering. The darker bands of the Oneida-Medina show specks of ocher on a fractured surface. These similarities often make it difficult to base arguments on the presence of such rocks over portions of the region, as the gneiss was universally overlaid by Potsdam west of the Saucon, and large areas of this formation still exist on the summits of the highlands in the position of deposition. The presence of rounded or angular fragments of sandstones and quartzites on gneiss may therefore be residual and not due to transportation, and their presence in abundance in the basal conglomerate of the Trias prohibits their use over that formation, as its limestone pebbles weather to a red clay and the rotten rock simulates some varieties of till, especially where the pebbles have been unstained.

The state survey reports † that the limestone belt is bounded above

* Report of Progress, Second Geol. Survey of Pennsylvania, D 3, vol. i, p. 72.

† See Report of Progress, Second Geol. Survey of Pennsylvania, vol. DD, chapter xvii.

and below by damourite slates, and that its lower portions are magnesian, as well as argillaceous and sandy; so that in the eastern part of the region (Bethlehem) it weathers to a clayey sand, and, in the western, to a reddish, porous sandstone that sometimes, when coarse, resembles the rotten bands of the flags in the Hudson river formation. This latter formation is well defined by the term "slate belt," as the above bands are thin and infrequent. The formations north of the Clinton occasionally carry fossils, and their determination is based thereon.

### GLACIAL DEPOSITS.

*The Fringe.*—The extramorainic deposits of the region are called a "fringe" to the moraine because they seem to be closely allied to it in time of formation, and not because they are attenuated. They are, on the contrary, of great bulk, and worthy of comparison with the moraine in its greatest extension. This will not be used as an argument for an extension of time necessary for their formation; but, on the contrary, the survey of the region shows such a recency of creation that we are compelled to admit great rapidity of accumulation, as advocated by Mr Upham, and, applying the same rule to the moraine, are enabled to compress all the glacial deposits into a short period that can be measured by tens instead of hundreds of thousands of years. It may be argued that such a bulk of material would not have escaped the attention of the state survey. The above extracts show what was done with the evidence adduced twenty years ago by Professor Prime, and it must be stated that local and limited surveys of the region are extremely confusing, and might lead to the decision that the deposits are due to water alone. It is only when the region is studied as a whole that the clue to the mode of action can be obtained. Any thorough search, however, would have shown subglacial till within the limits of the region mapped; but this was so capped by lake deposits as to be unseen except under special circumstances. There was no reason, however, for calling the unstratified till to be found in railroad cuts at Bingen, South Bethlehem, Northampton, Siegfried, and other places stratified material; though it is not common to find subglacial and englacial till composed almost wholly of river pebbles, and on this account an extended discussion of the till and the capping is necessary.

*The Packer Clay.*—A lake formed by the damming of the Lehigh by the glacier was noted on the map within the contour line of 500 feet. It is proposed to call this lake Packer, in honor of the late Honorable Asa Packer of Mauch Chunk. Judge Packer, as the builder of the Lehigh Valley railroad and the founder and munificent endower of the Lehigh University, was preëminent in the development of the region mapped

and over which the lake existed. This lake was 26 miles long and 9 wide, with a bay (in the Saucon valley) 11 by 3 miles. The Lehigh flowed for 20 miles from Mauch Chunk through slack water, with an average width of three-fourths of a mile before reaching it, and there were long bays in the valleys through which Aquanchicola, Lizard, Mahoning, and Big creeks flow. Evidences of the elevation of the surface are found in sudden stoppages of the lake formations at the 500-foot contour at Parryville, Bath, the west side of the divide at Stouts, and the terrace at Lehighton, before named, as well as one at South Bethlehem. As the area is extensive, there may exist many more evidences not yet discovered; but sufficient work has been done to prove the existence of the lake. This varied in size and depth from two causes: the occupation of a variable portion of its bottom by the glacier, and the variation in the ease of drainage. There were two lake periods, and only the latter has left any traces. When the glacier advanced to the mouth of the Lehigh it began to form a dam under which the water escaped, and as it advanced subglacial drainage became more and more difficult. In time the ice filled the bottom of the lake and crossed the Topton divide and the first period came to an end. The second began when the ice retreated across the same divide, and continued till it had freed the mouth of the Lehigh. In both periods there was generally slack water upon which floated the bergs from the ice-foot, and in which settled the débris brought down by subglacial streams and bergs. During the first period the lake was a catch-basin to accumulate, on its old preglacial bottom, a mass of clays and sands which were scraped from the decomposed soils north of the Blue ridge and at that time covered by the ice, and mixed with a huge bulk of river and glacial gravels brought down by the Lehigh, whose drainage area was crossed by fifty miles of the ice-front. The advancing ice ploughed into this mass and forced it up the southern shores of the lake and over the eastern part of the Archean highlands to form thick beds of till which will be described later. The water was 150 feet deep over Bethlehem hill, and 280 feet over the Lehigh, so that the buoyant effect on the glacier was great and the corresponding erosion diminished. We find deep remnants of decomposed rock at Bethlehem and South Bethlehem due to this cause. The evidences of this first period are, consequently, wanting, and we find only the accumulations during the retreat of the ice.

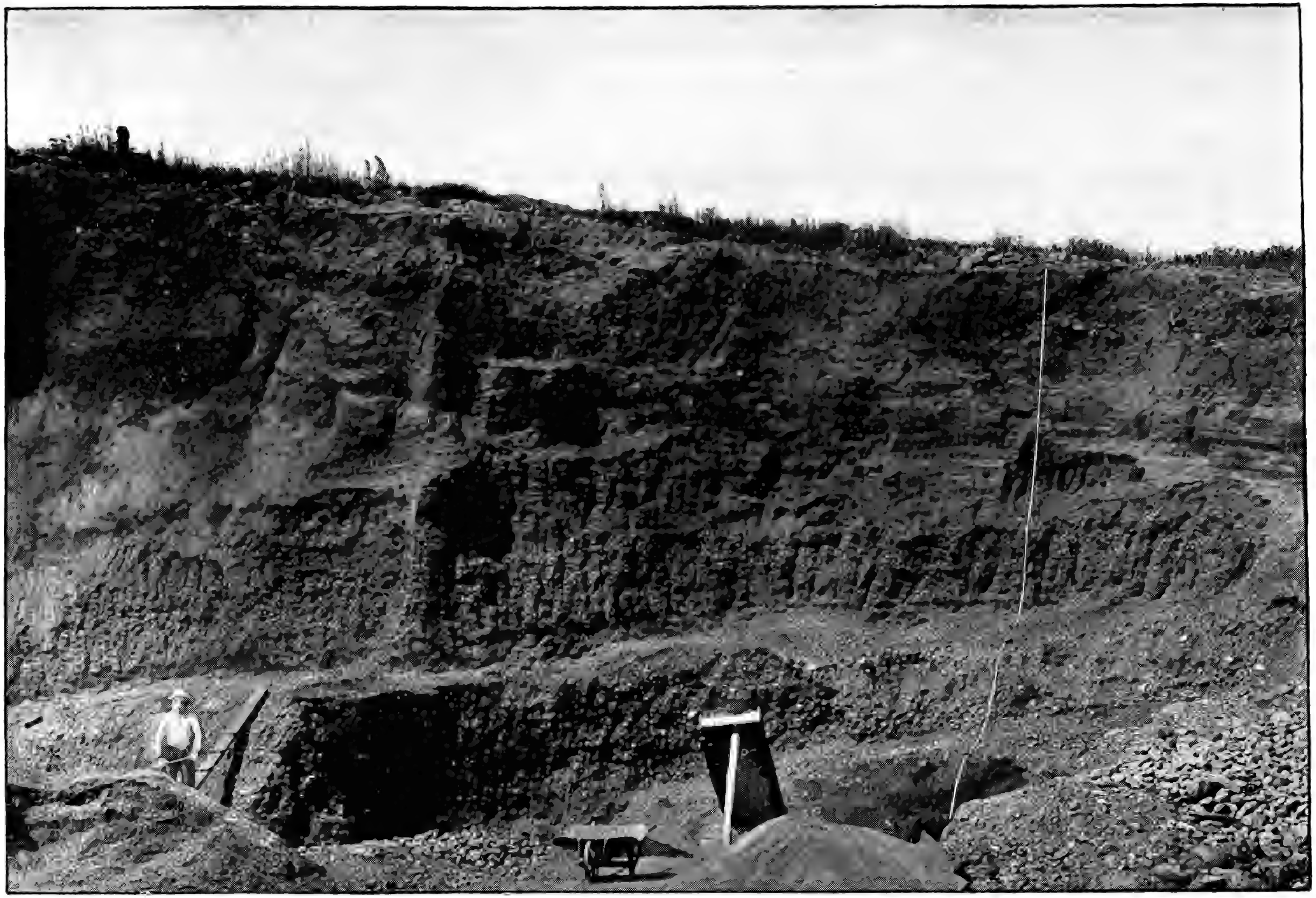
The Packer clay is, therefore, a local deposit existing between Easton and the Topton divide and below the level of 500 feet, with the exception of the part of the Saucon valley west and south of Hellertown. Here there is no cap over the till, and this absence proves the previous statement that the Leithsville divide was higher than that at Topton at

this time, and that there was no escape of the waters into the Durham valley and the Delaware. A flow over that divide would have distributed the clays over the Saucon valley in great bulk. On the Topton divide the state of the clay indicates slack water, so that there was no extended discharge over that divide, and any evidence of slight flow has probably been washed away from the steep sides of the Sacony valley. The drainage of the lake was therefore subglacial.

The clay is generally a reddish brown, unstratified, sandy deposit, with a burden of glaciated, angular and river-rolled material scattered irregularly through it. Very few striated stones have been found in the sections studied, and the bulk of the burden consists of river cobbles and pebbles, with a considerable proportion of perfectly angular fragments derived from the rocks to the north of the locality where they occur in the clay. In the case of syenitic fragments, they occur near the South mountains, where they could have been picked up by shore ice and carried a short distance. The greater proportion of the burden, however, are sandstones and chert, with a small amount of limestone and slate. The specimen of striated rock exhibited is from the clay, and shows the general freshness of the burden. The slates are generally fresh within if oxidized externally, and workable slate can be found 10 feet from the surface, whereas the average depth of decomposed soil over an unglaciated area, or one exposed to long atmospheric action, is from 60 to 75 feet.

The clay deposit varies from a perfectly clean clay to clayey sand as we go from the deep water of the south to the northern shallows. It is generally unstratified, but shows local areas of stratification. Its thickness varies from a few inches to twelve feet at West Bethlehem, but the general average is three feet. The stony burden thins out along the shorelines and is replaced by the washings of local rocks or of the till left by the ice. Where the clay is stratified it caps stratified sands and gravels, as at Alburtis, of local extent, and due to local variations in currents from the land drainage.

The Packer clay may have been augmented by slight additions over low levels from dams in the Delaware narrows after the mouth of the Lehigh was free, as there are clays in the Durham valley which are at lower levels than those in the Lehigh and which could have been made by ice-dams in the narrows or by the damming of the valley by the glacier. As soon as the ice freed the mouth of the Lehigh the front was but a few miles south of the great moraine, so that the Packer clays slightly antedated as to their top parts that formation, and the clays in the small valleys from dams in the narrows may have been contemporaneous. By reason of the recency of the deposits, we can claim that



RAUCH'S GRAVEL PIT, WEST BETHLEHEM, PENNSYLVANIA.

the moraine represents the next formation above the clay as truly as if deposited as its cap.

The high state of oxidation of the clay has been adduced as evidence of its great age, but the argument is worthless in view of the manner in which it was accumulated and the condition of the burden it carries. These glaciated, rolled and angular stones are generally fresh and unoxidized, as just described. We have, therefore, a highly oxidized clay throughout, bearing at all levels fresh material. The mixture is no older than the fresh part, and the oxidation of the clay is either preglacial, from its having been part of the soil of the region (as gneiss, limestone and slate all rot to just such a clay), or due to oxidation while it was being deposited. Judging from the state of certain portions of the till, the chances are in favor of the former supposition. These fresh fragments antedate the great moraine and show that it also is of recent date. It may be argued that the clay is the ordinary bowlder-clay of subglacial origin. If it were its deposition would have disturbed the stratification of the underlying gravels and sands, and there would not be the great proportion of angular fragments in the burden, nor, further, would we in hundreds of cases find the till shading gradually and conformably into the overlying clay.

*Drumlins, Kames and other glacial Phenomena.*—As the clay cap hides the greater part of the region, except where cuts have been made, few buried deposits of the types specified have been found. It has not been fully determined whether the ridges of unstratified gravel at Bingen, Siegfried, Northampton, etcetera, are drumlins or portions of lateral or terminal moraines. The two latter deposits are on the north bank of the Lehigh and are 10 to 20 feet thick, from half a mile to one mile long, and from a few hundred feet to half a mile wide. The chances are in favor of their being drumlins and connected with the subglacial drainage of the region.

Rauch's gravel pit at West Bethlehem is a stratified (plunge and flow) deposit varying in thickness from a few inches to 30 feet, as far as known. Its thickness may be greater to the west, and it pinches out to the east and south by the erosion of its surface, and to the north by the rising of the underlying rock. The clay cap is continuous over the whole, but is twice as thick at the western end, so that both deposits seem to have been influenced by similar forces, but at different times, as the clay is unconformable. Plate 10 shows the central third of the north face of Rauch's pit. The unconformity between the clay cap and the gravel is plainly marked, as well as the thinning of the deposit toward the east. The darker smooth surface over which the lower end of the tape lies is the glaciated remnant of decomposed calciferous sandstone that preglacially

capped the region. No subglacial till is shown. The bed of gravel lies on the eastern end of the southern side of a ridge and where it falls rapidly to the Manokisy. A section through the ridge shows that the underlying rock has lost its decomposed cap on the northeast slope, which rises fifteen to one, and up which the ice came, but retains it to a great depth on the southern side (with a similar slope), down which the ice passed to the Lehigh, 130 feet below. From this it seems that the ice could not accommodate itself to the sudden angle in the ground, and an arch must have been formed on its under side, with the usual crevasses, so that the pressure was not exerted till just before reaching the Lehigh. This stretch of ice was from 150 to 280 feet beneath the lake surface, and the arch was used by the lake waters in their escape toward the Delaware. The ground falls rapidly on the northern bank of the Lehigh from Allentown to Easton, and the existence of similar deposits in places along this line and just north of Hellertown, where the waters from the Saucon valley would attempt to escape (and along a similar ridge), lends strength to the theory of the formation of these deposits by subglacial drainage. During the advance of the ice there was no stability to the deposit, and it was continually carried away by the moving ice, as is shown by the finding of thick subglacial till beneath the gravels and above the decomposed limestone; but this conclusively proves that the till acquired a great part of its river gravels from this source. This gravel deposit is not a river bed, as there is no continuous deposit across the Manokisy at Bethlehem, and it was formed after the advent of the glacier and before the deposition of clay, as it is enclosed between till and clay. It probably began to accumulate after the motion of the ice had ceased and before it had melted over the spot. The subglacial waters would increase the size of the arch under the ice, and stratification went on proportionate to the dissolving of the ice. When the ice was completely removed erosion began and continued till the ice-foot had retreated for some distance down the ridge, and when slack water occurred and the clay began to deposit, the eastern end had been cut off, and the clay rested unconformably on the eroded surface, as can be seen in plate 10. It remains to note that when Mr Lewis * visited the place there were no bowlders in sight in the gravels. Their occurrence is not common, but one, of a spindle shape, is now exposed on the western side of the pit and about fifteen feet from the top of the gravel.

We have, therefore, a stratified gravel on the south side of the ridge capped with clay, and a glaciated and fresh rock surface similarly capped on the north side.

*The Till and its Age.*—This exists as ground, lateral and terminal moraines. The first varies from the ordinary formation by the persistent

* See Report of Progress, Second Geol. Survey of Pennsylvania, D3, vol. i, p. 48.

EAST SIDE RAUCH'S GRAVEL PIT, WEST BETHLEHEM, PENNSYLVANIA.

mixture of river gravels, as before described. Removing them, it resembles ordinary subglacial till, and is found as a mass of angular local fragments or of local paste. The weathering of tills proceeds under the same laws as of ordinary rock of the same nature, only the broken character of the till invites greater rapidity of decomposition. An old till of limestone or slate will show a clay top that protects to a certain degree the lower parts until the whole mass is resolved into clay. The deposit over this region is not an old till, as there is a constant uniformity of oxidation and decomposition on a vertical section, no matter what the thickness may be. It is frequently found perfectly fresh, as under the gravel just described, where it is a paste of damourite, holding perfectly fresh and firm fragments of the same rock and river pebbles unoxidized. It rests on the old, rotten, Calciferous sandstone, and the contrast of the light colored till, with its fresh fragments and pebbles, and the soft, yellowish red, underlying rocks (lead colored when fresh) is seen at once, even if there were no sharp line of unconformity between the two.

Plate 11 shows the lower part of the gravel and the upper 18 inches of till as exposed at the southeastern corner of Rauch's pit. The sequence is, sandy clay cap, 1 to 3 inches; gravel, 2 feet; till of damourite paste, inclosing fragments of the same with rolled, but not striated pebbles, and having local patches of sandy nature, 2 feet. These rest on decomposed Calciferous sandstone from which the preglacial surface has been removed. The thin sandy cap and underlying gravel have lost part of their coloring matter by leaching, with the resultant formation of a conglomerate in the lower inch of gravel, having a limonite matrix, which is seen sharply projecting over the till at the left upper corner of the plate and running diagonally to the right. The ferruginous solution has penetrated the upper surface of the till to the average depth of one inch and the sandy parts to a greater depth, while the body of till remains fresh in color. As the country rock is Calciferous sandstone, the presence of damourite indicates foreign origin of the till, and its freshness under conditions that favor oxidation compels the conclusion that the period of exposure has not been long.

Locally the till is composed principally of gravels,. South of the Blue ridge they are 25 feet thick and freely mixed with huge bowlders, and from Seidersville to Temple they form a huge lateral moraine which extends along the northern border of South mountain. One section gives 70 feet of thickness. The average thickness of the till, however, is 3 feet. Immediately south of the Ridge it is not only thick, but rests on the crushed and bent surfaces of the slate, and has but little local rock in its composition. The slate increases in proportion as we go south, and finally forms the bulk of the mass; but the gravels and foreign rocks

never entirely disappear, and are found continuously to South mountain. Such a section has been traced from Germansville through Pleasant Corner, Lowhill, Foglesville, Trexlertown and Alburtis. The crushed and bent slates are carried almost across that formation, and slaty till in a perfectly rotten state is found on fresh limestone just north of Foglesville. The large bowlders are carried over several steep ridges, but could not surmount that south of Switzer creek, so that the rest of the region is free from very large stones. The county bridge over the Jordan near Pleasant Corner is built of large cut stones from the bowlders brought over the Blue ridge, and the latter are as fresh as if recently taken from the quarry. Those with a calcareous matrix must be of recent formation, as an extended exposure reduces them to sand.

Over the limestone belt the till is a bowlder-clay of a reddish brown to reddish yellow color, carrying a few pieces of the country rock; but the burden is mainly fragments of chert, rolled quartz from the slate, and foreigners from and beyond the Blue ridge. East of the Lehigh we find the gravels and bowlders scattered over Northampton county, and a number of lines of stones across the Saucon valley mark the short stoppages of the ice on its retreat; but west of the Lehigh there is but little gravel and few bowlders over the limestone and the lower part of the slate, but slaty till is found on slate, and limestone fragments and clay on limestone. The moraine lines in the Saucon show that the ice moved southwest originally, but the change in the trend of of South mountain exerted a pressure on the glacier and altered its direction to one parallel to the axis of the valley, as shown by the distribution of the till just noticed as well as by the shape of the lowest and most southern range of slate hills, whose longer axes and slightest slopes are parallel to the direction just mentioned. The ice-movement was, therefore, southwest until the pressure of the ice heaped against the northern flank of South mountain resulted in a more westward motion. The melting of this accumulation formed the great lateral moraine that we find between Seidersville and Temple. It is shown in the railroad cuts at Emaus, Topton and Temple and consists mainly of pebbles of sandstone, with a small amount of trap and gneiss. These are seldom larger than the hand and the finer part of the till is more sandy than clayey. At Topton the cut is 17 feet deep, and just beside it is a well sunk in gravel for 80 feet before striking limestone and water. This would make the thickness nearly 100 feet. At Temple the cut is 20 feet deep and a well near by is 97 feet deep, but no record of the material passed through or the depth of the limestone could be obtained. The well-top is much below the track, so that the bottom would be about 150 feet below the level of the top of the gravel. This will be again referred to.

The till has been traced to the Schuylkill at Ontelaunee station, on the Pennsylvania railroad. There is a clay in the northern part of Reading that may be bowlder-clay (subglacial) or due to ice dams, or perhaps to decomposition of the local limestone. There are a few evidences that the ice swung round the end of South mountain, but they are not conclusive. The traces of ice-invasion become dubious over the western end of the slate belt until we reach Jacksonville, where the thick masses of gravel and bowlders are again found. The presence of the ice at this point and at the Schuylkill shows that it must have covered the region between them. The next point to be studied is the extent of the invasion beyond the Schuylkill and the point where its edge crossed the Blue ridge. It is evident that ephemeral lakes were formed by the damming of Lizard and of Mahoning creek, and two moraines have been found crossing the valley of the former. In the eastern border it seems that the ice did not cover either the Hexenkopf or Bowers rock, as it had wasted its power in surmounting the ridges north of them. These two peaks divided it into an eastern lobe which crossed the Durham valley; a middle one which crossed the Saucon valley as far as Center Valley, but did not go west of a line between that place and Friedensville; and a third which crossed the range back of South Bethlehem (850 to 920 feet), but was turned westward by Bowers rock (1,020 feet) and went as far as the Schuylkill. The southern border on the Trias has not been fully determined, owing to the similarity of some of the till to the rotten basal conglomerate of the Trias, but it is hoped that the trap pebbles and glaciated outcrops may settle the matter in the absence of fossiliferous foreigners.

The age of the till has been briefly discussed in the American Journal of Science for January, 1894, so that only a summary is necessary here. We find:

First, that the comparison of fresh glaciated surfaces with the remains of preglacial decomposition shows that the former were recently eroded.

Second, that the Packer deposits represent mainly preglacially oxidized material, and their burden is generally fresh.

Third, that the freshness of surfaces and burden must be balanced against the bulk of the deposits, for if the freshness indicates recency, the bulk stands for rapidity.

Fourth, that when the ice-front freed the mouth of the Lehigh it was almost in the position where it formed the great moraine. This latter may, therefore, be taken as a continuation of the work of glaciation in the region, and we can apply the same rule of recency and rapidity to it.

Fifth, that the scouring out of a filled gorge of the Lehigh is disproved by finding the till and clay running uniformly from the top of Bethle-

hem hill to the river. As the Lehigh is a stream of great volume and velocity, and since the filling remains as it was deposited, the postglacial interval has been short.

### *THE UNDERLYING ROCKS.*

In a few instances the surfaces are the remains of preglacial decomposed country rock left by the ice, as before noted, but the great majority of exposures present glaciated and fresh country rock. The freshness may be attributed to a denudation that has kept pace with decomposition, and this might be plausible were the rock homogeneous and there existed no remnants of decomposed material for comparison. With ordinary rocks there is little difficulty, even in the absence of striation, and striation is uniformly absent over the region, in discriminating between a glaciated surface and one etched by subaërial denudation. The latter force would not work equally, however, under the varying caps of gravel, sand and clay or all combined, and the equality of erosion points to glaciation, while the freshness of the rock speaks of recency, as well as does the comparison of the fresh and rotten forms of the same rock on either side of the West Bethlehem ridge. There are thousands of these fresh exposures, capped and uncapped, and they are of gneiss, limestone, sandstone and slate, so that the vaying rapidity of decomposition of the rocks can be adduced as an argument for recency also, as all are equally fresh.

### *PREGLACIAL SURFACES*

A statement has been previously quoted that the Aquanchicola has cut a new bottom through the solid Clinton shales since glacial times, and another quotation stated that the Lehigh had made extensive cuttings in the same interval. Both are inaccurate. A study of the first locality shows rock across what was called the preglacial channel and above the present level of the river. The rock cut that is thought to be the new channel is several hundred feet long. On the rock across the "old channel" lies a thick bed of stratified sands capped by an equally thick bed of Packer clay. In the first place, we are asked to believe that the stream found it easier to cut through solid rock than to wash away an equal amount of light sands and lighter clay; in the second, we find that the deposit of sands and clay never was as high as the supposed barrier of solid rock, for the till has been traced to the tops of the two sides of the creek, and also the capping of clay almost to the 500-foot line. Both till and clay are found on the sides of the "new rock channel," and in the case of the till from within five feet of the water's edge to the top of the cut. This shows that the present channel of the Aquanchicola is preglacial, and that the stream probably always flowed in that

direction through what was probably one of the many slight faults that are found at the gap, while the sand dam probably always existed where it is, owing to the fact that the Lehigh and Aquanchicola meet "head on," and the greater force of the Lehigh would neutralize the smaller stream and form a bar across its mouth, so that it would be deflected to the south and widen the crack made by a probable fault. However that may be, the channel is as it existed during glacial times.

From Whitehall southward, along the Lehigh, both till and clay are frequently carried to and below the flood-plain deposits, and at West Bethlehem the clay extends continuously down the hill to the river. The flood-plain is covered with a thick, unstratified gravel, through which the railroads on both sides of the river have deep cuts. The new well for Bethlehem, at the level of the Manokisy, passes through 13 feet of gravel before striking limestone. Preliminary piling to settle the location of the 120-ton hammer of the Bethlehem Iron Company on what was a part of the old river bed of the Lehigh showed that the solid rock, or what resisted as such, was 26 feet deep, on the average, over an area of 75 feet by 75 feet. Subsequent results—a sinking of four feet—after placing the hammer showed that solid rock had not been struck, and excavations for various purposes developed the following section:

River gravels—a few inches to 14 feet.
Packer clay—3 to 4 feet.
Gravel (till)—bottom not reached, owing to influx of water.

The piles struck bowlders in sinking, and some of them were driven 36 feet. We have, therefore, a buried glacial or preglacial channel, instead of an eroded one, and, as before stated, this is along that part of the river where the fall is the gentlest. The river has never been able to clear out its glacial filling, except at the point where it falls to meet the Delaware. A section across the river at Bethlehem shows the fresh and solid rock rising just north of the river, in the new Nisky cemetery, and fifty feet above the water, and also rising just behind the iron works in South Bethlehem to the same height. Here we have a deep gorge of preglacial origin, and studies along South mountain show that this probably extends from Easton to the Schuylkill, with equally steep walls, as we find the wells over the gorge from 70 to 120 feet deep, while on either side at no great distance the solid rock outcrops. A section from Trexlertown to Alburtis starts from the middle of the limestone valley at 370 feet, with the rock 20 feet deep, and in three miles we find the rock at the surface at 420 feet. A short distance further and we are at the edge of a deep limonite mine, and this depth of fill continues till we cross the railroad, when the rock outcrops on the slopes of South moun-

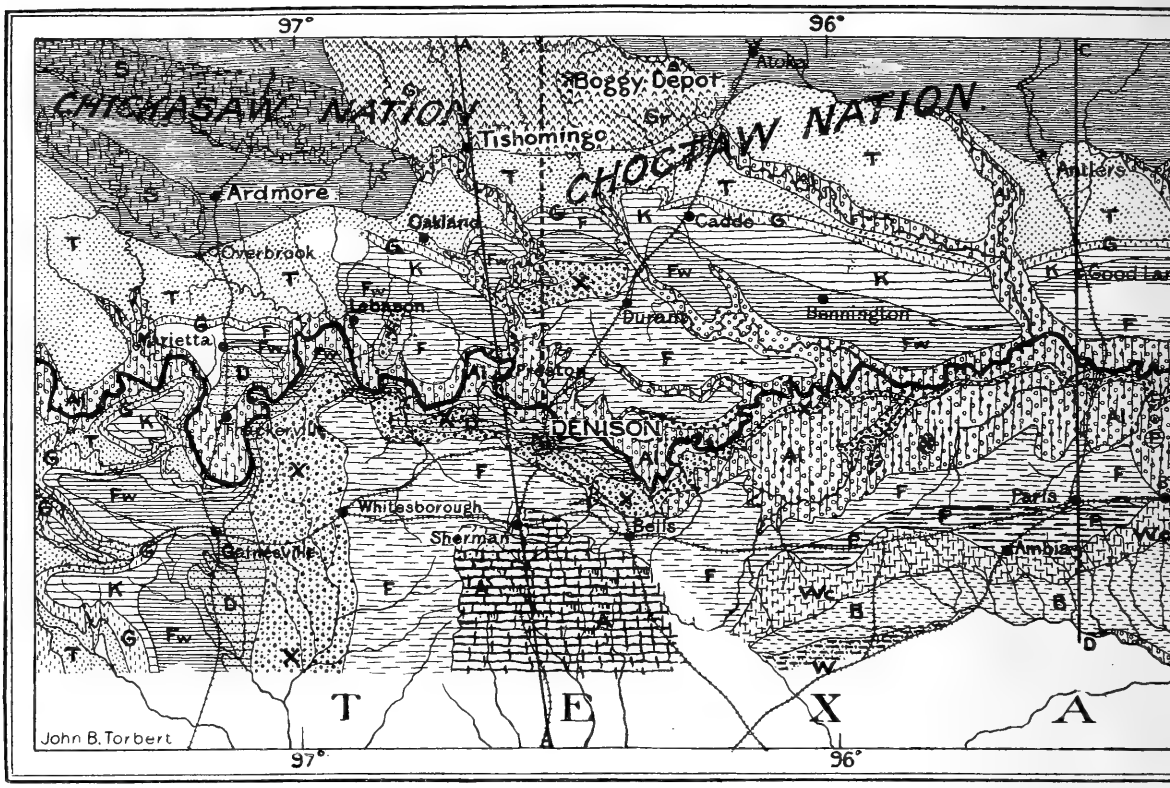
tain. Sections at Alburtis (420 feet) and Trexlertown (370 feet) show similarity of deposits as follows:

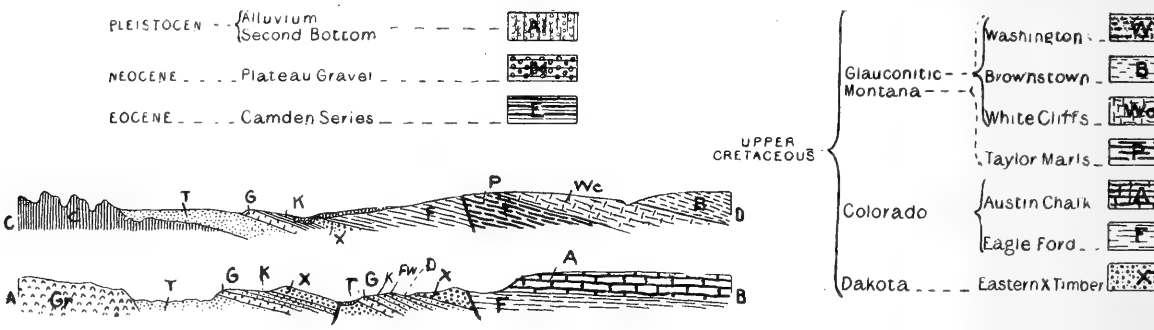
| | *Alburtis.* | *Trexlertown.* |
|---|---|---|
| Unstratified red clay | .. | 30 inches. |
| Stratified sand and clay | 27 inches. | 10 " |
| " clean clay, jointed when dry | 7 feet. | 16 " |
| " clay and gravel with rolled limonite | 31 " | 4 feet. |
| Till with cobbles and bowlders of Oriskany, etcetera | 10 " | 11 " |

The difference between the nine feet of Packer deposits in the mid-valley and the thirty-nine feet on the shallows bordering the Archean highlands is caused by the drainage from the latter, as the watershed is two miles back of Alburtis, and the amount of water precipitated was considerable. Instead of a cutting down of the country since glacial times, therefore, we find that the preglacial surfaces are generally covered by a clay cap, or an accumulation of gravel, and Professor Prime's theory is fully proven.

## Summary.

The clays are the work of ice in slack water, and thus far no signs of life have been found in them; they were deposited immediately after the retreat of the ice, and the oldest are at the western part of the lake; their burden and that of the till shows recency of formation, as do the outcrops. We may conclude that the great moraine was formed immediately after the withdrawal of the ice from the Lehigh, and that it and the extramorainic deposits of the region were part of the same ice-invasion, which was of recent age and short duration.

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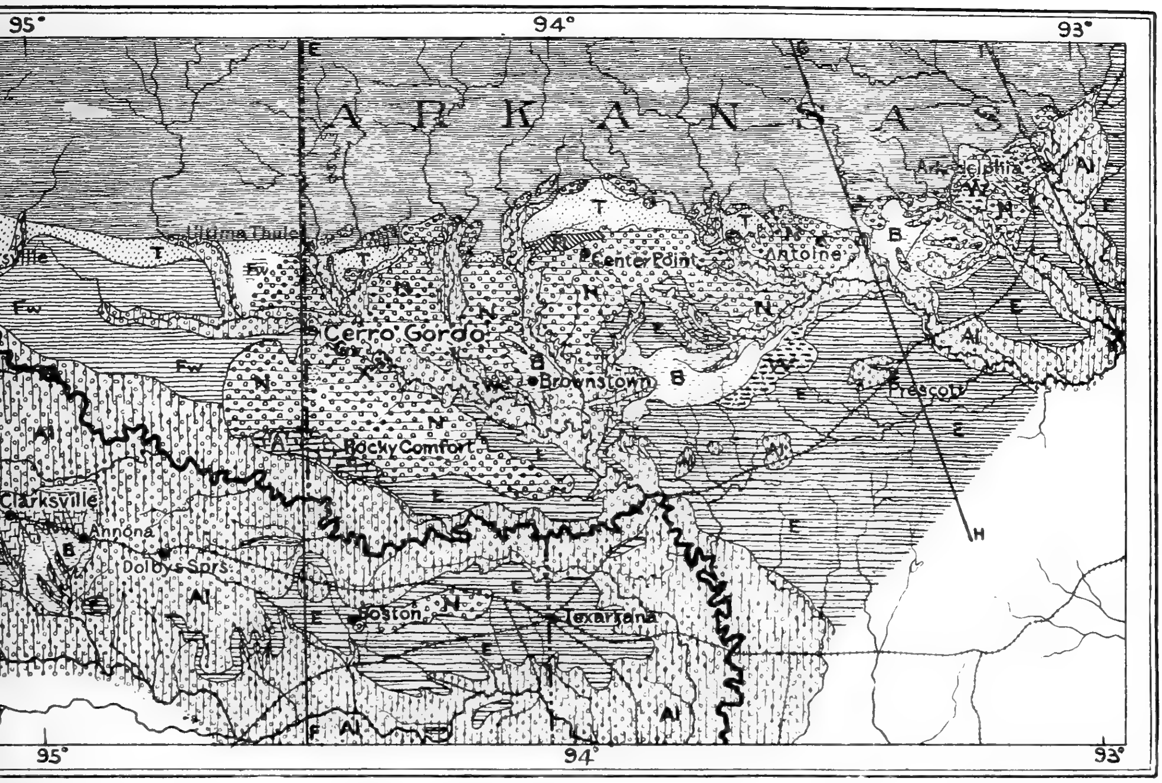
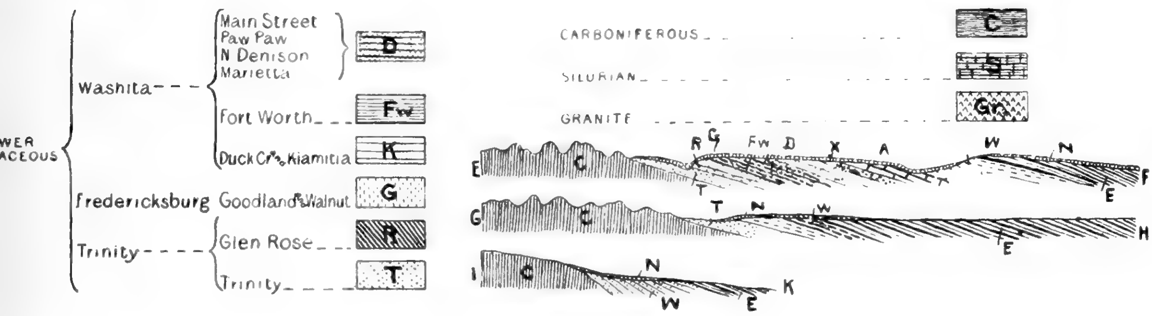
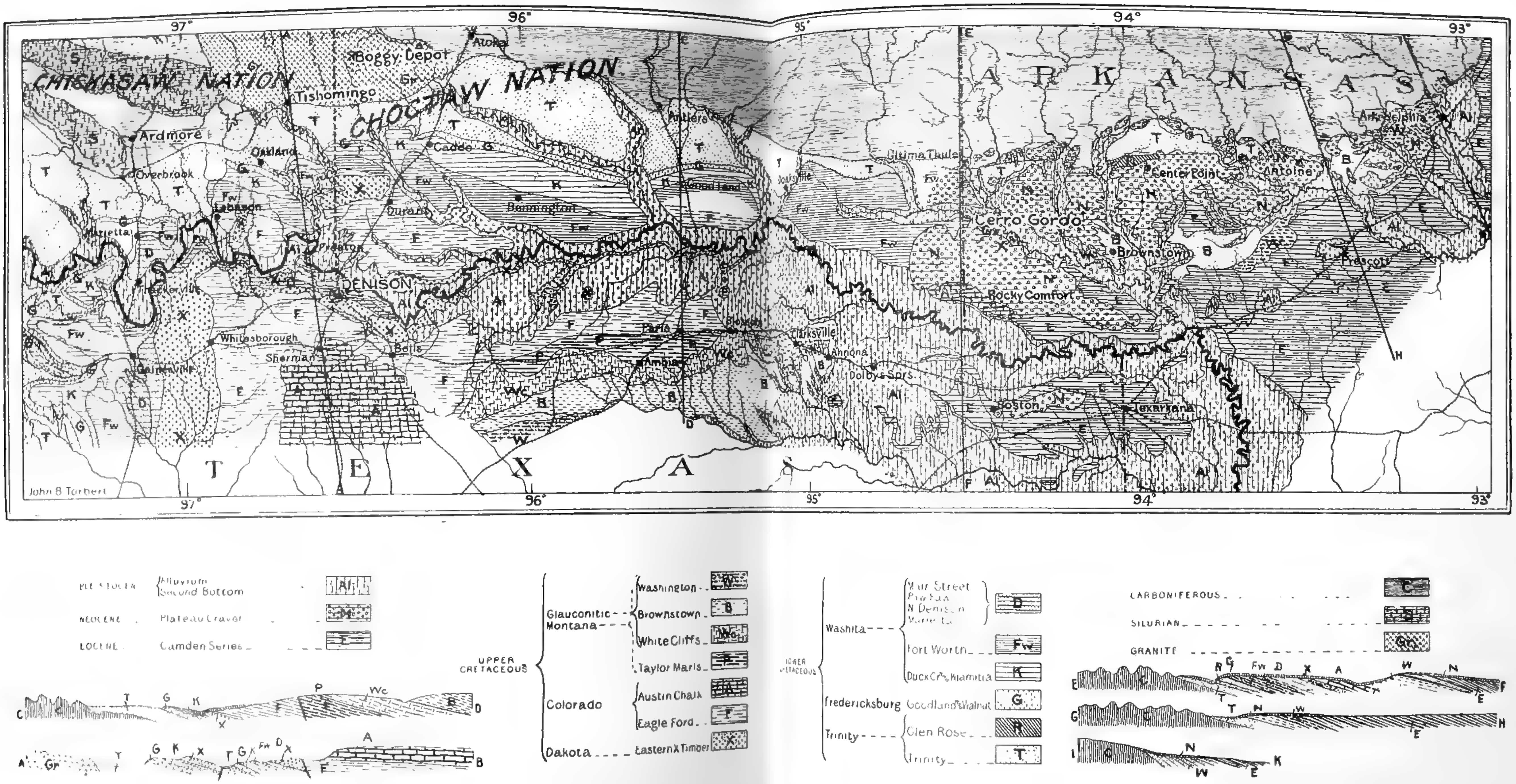



ORY AND ARKANSAS ADJACENT
BY ROBERT T. HILL.




GEOLOGY OF PARTS OF TEXAS, INDIAN TERRITORY AND ARKANSAS ADJACENT TO MEDIAL PORTION OF RED RIVER.—BY ROBERT T. HILL.

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# GEOLOGY OF PARTS OF TEXAS, INDIAN TERRITORY AND ARKANSAS ADJACENT TO RED RIVER*

BY ROBERT T. HILL

*(Read before the Society December 29, 1893)*

## CONTENTS



* This is the last of a progressive series of short papers by the author on the geology of the Texas region, and contains his final classification of the Cretaceous formations. A list of the papers in which the story as a whole is told is given on pages 337, 338.

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## Comprehensive Position of the Region Geologically.

Although Red river is one of the most important of the western rivers, its adjacent territory has not been thoroughly explored or surveyed. In 1852 Marcy's expedition reached the river at Preston, near the western border of the region discussed in this paper, and proceeded from thence westward to the headwaters of the stream. Its lower portion, east of the Texas-Louisiana line, has been reported upon by various engineers as to its navigability. The medial portion between these points has not been seriously studied, and little has been written upon the geology of the adjoining country. La Salle, De Soto and other early pioneers crossed this portion of the river previous to the present century. Here Nuttall botanized, and Catlin painted some of his most interesting portraits of Indian life.

The only early pioneer geologists who touched the area were Dr G. G. Shumard and Jules Marcou, the latter reaching it at its northwest corner. Their contributions were of that class of fragmentary but important descriptions which cannot be overvalued.

In the years 1887 and 1888 it was my privilege to make a rather thorough survey of the southwestern portion of Arkansas, and during previous and subsequent years I made frequent reconnaissance into the Choctaw and the Chickasaw Nation* and the opposite counties of Texas. This portion of our country is of exceeding geologic interest, in that here the peculiar geographic features of the Texan and Cordilleran region make their final disappearance eastward toward the Mississippi river and meet the geologic and geographic features which belong to

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* In this region the term "nation" means the area in Indian Territory occupied by an Indian tribe, and it is so used in this paper.

that portion of the Atlantic coastal plain known as the Mississippi embayment, while on the northward the whole is limited by the Ouachita group of mountains, which are distinctly Appalachian in age and structure. In fact, the area embraced upon the accompanying map represents a base, away from which the different features of Texas expand to the south and southwest.

The eastern half of this area, including southwest Arkansas, Choctaw Nation and Bowie and Red River county of Texas, is one of the most difficult for exploration. The littoral terranes of different ages are all of an unconsolidated ferruginous nature, and it is only by long and careful study that they can be distinguished one from the other. At the first glance, the Trinity sands so much resemble lithologically the Dakota, and the Eocene so closely simulates the Plateau gravel and the Second bottoms that one would think them the same. The problems are somewhat similar to those met in studying the later formation of the North Atlantic coastal plain, except that they are much more complicated by the great bottoms and flooded rivers, and absence of any topographic maps, to say nothing of dense forests, excessive humidity and malarial climate. Upon the other hand, the area represented by the western and southern portion of the map is a beautiful prairie region, with simple and conspicuous stratification, diversified by strips of timber—a country radically different in every respect from the eastern part.

## Physiographic Features.

*Topography.*—The northern border of the region is limited by the Ouachita mountain system, which, with its vertical folds and consolidated rocks of Paleozoic age, forms a northern barrier to the geologic features of the region to be discussed.

South of Red river the low, rounded divide of Red and of Sulphur river extends eastward, but is devoid of sharp topographic sculpture, thereby differing from the Kiamitia prairies north of the river. It consists of a low central ridge of rich prairie land, diminishing in area eastward, with timbered slopes and valleys. This prairie is mostly the outcrop of the uppermost Cretaceous formations.

The Kiamitia prairies and gravel mesas lie north of Red river and south of the mountains. The former are small, flat calcareous prairies, interrupted by scarps and bounded on all sides by forests. To the eastward, in Arkansas, they are supplanted by extensive low mesas, capped with gravel. The Kiamitia prairies are the outcrop of Lower Cretaceous beds.

The Red river valley, the representation of which extends longitudi-

nally across the map, is bordered with many ancient terraces or deposition planes.

The following features, although secondary to the above, are also of importance:

The Antlers (Trinity) valley is a low topographic groove extending parallel to the foot of the mountains. It is a valley of headwater erosion.

The Goodland escarpment, which limits this valley to the southward, forms the northern scarp of the prairie region and is an escarpment of stratification.

Extensive second bottoms of the streams or benches are found above their present levels.

The eastern Cross Timbers are erratic belts of timber occupying the upland and confined to the outcrop of certain arenaceous terranes.

The genesis and relation of these topographic features will be brought out in the course of the geologic discussion.

*Drainage.*—The valley of Red river everywhere represents the lowest drainage channel, but there is also an extensive secondary system of drainage coming down from the mountain region on the north and flowing southward into Red river. No survey of this has been made in Choctaw Nation, but it is equally diversified there as in the Chickasaw and Arkansas portion of the area. This drainage is marked by the large proportion of water to the length of the streams and its excessively wide bottoms as we approach the level of Red river. South of Red river an entirely different and probably newer system of secondary drainage is met, flowing directly away from Red river and into the Trinity and the Sulphur.

*Forest Growth and its Relation to geologic Structure.*—One of the most instructive features of this region is the relation of forest growth and prairie to geologic structure, and its bearing upon the southwest termination of the great Atlantic timber belt. The rainfall is everywhere here sufficient to produce abundant arborescent growth, as shown by the belts of timber crossing it, but the region is varied by sharply defined prairie and forest areas, the distribution of which is entirely in conformity with the peculiarities of geologic substructure.

The prairie regions are of five kinds:

1. The Prairie d'Ane type. Small open spaces in the heart of the great Atlantic timber belt, surrounded everywhere by the forest growth of virgin Appalachian flora. These prairies conform in area with the extent of the fresh-water Pleistocene deposits of the Prairie d'Ane type, namely, prairie d'Ane, prairie de Roan, and Bois d'Arc prairie of Arkansas, and New Boston prairie of Texas. They are usually surrounded by a growth of liquidamber.

2. Prairies coincident with the distribution of the medial beds of the Upper Cretaceous, occupying the outcrop of the Benton, Niobrara and Taylor (*Exogyra ponderosa*) beds, clays and chalks, the residual soils and compact calcareous subsoils of which seem ill adapted to forest growth.

3. Prairies of the Comanche series, occupying the calcareous and argillaceous terranes—all of the beds, in fact, of the Comanche series except the Trinity, Paluxy and the upper Denison sands. It will be noted that these beds outcrop as prairies even when they occur as isolated areas in the Tertiary forested region.

4. Prairies of the Carboniferous clays of central Indian Territory.

The forests are of the following kinds:

1. The western part of the Atlantic timber belt proper, consisting of (*a*) pines on the post-Cretaceous gravel and sandy terranes, and (*b*) of hardwoods—oak, ash, hickory—in the second bottoms and bottoms of the streams and upper part of the Cretaceous formations.

2. Westward-extending tongues of the great Atlantic timber belt, alternating with prairies, following up the sandy alluvial riverways or, on the upland, following the strike of the arenaceous terranes. The latter are almost invariably oaks and elms. These upland timbers follow four formations: (*a*) The vertical sandstone beds of the Carboniferous, the clay beds between being prairie. (*b*) The Cross Timber belts, following the Cretaceous sands. They are exactly coincident with the outcrop of the Trinity, upper Denison and Dakota sands to be described. (*c*) The glauconitic sands of the uppermost Cretaceous carry hardwood forests coincident with that formation. (*d*) The Bois d'Arc forests of the Kickapoo (glauconitic marls) only occupy these beds of the Upper Cretaceous in southwestern Arkansas and northeastern Texas.

When botanists thoroughly study the region they will see that the minor flora is likewise proportioned to formations, and that the structure and chemical composition of the different beds in this region, aside from altitudinal variation, produces the greatest differentiation of floras.

## Geologic Formations and Succession.

I have already described in previous papers, and attempted to émphasize the importance of, the mountain system which, a little south of the center of Indian Territory, extends east and west between the Canadian, the Arkansas and the Red river drainage, and also presented some of its geologic features, showing that in its eastern portion at least it is of typical Appalachian structure and belongs categorically to the Appalachian geology of the United States.

The southern front of this mountain region has been the scene of a continued struggle between the land and the marine baselevel of the gulf of Mexico, and in the sediments to be described is recorded the details of this history, and by the aid of which we can interpret many phenomena of the Texan and Mexican region to the westward, the legibility of which has otherwise been obscured there by the great orographic and denudative agencies.

The following beds, occurring in the medial Red river region, have been largely deposited against this old Paleozoic shore:

| | | | |
|---|---|---|---|
| Pleistocene and recent | | Alluvium. | |
| | | Second bottom. | |
| Neocene | | Plateau gravel. | |
| Eocene | Camden series. | | |
| Upper Cretaceous | Glauconitic division | Washington. | |
| | | Brownstown. | |
| | | White Cliffs. | |
| | | Taylor marls. | |
| | Colorado division | Austin chalk. | |
| | | Eagle Ford. | |
| | Dakota division | Eastern Cross Timber. | |
| Lower Cretaceous | Washita division | Main street | Denison beds. |
| | | Paw Paw | |
| | | North Denison | |
| | | Marietta | |
| | | Fort Worth. | |
| | | Duck creek | Preston beds. |
| | | Kiamitia | |
| | Fredericksburg division | Goodland | Comanche Peak beds. |
| | | Walnut | |
| | Trinity division | Glen Rose. | |
| | | Trinity. | |
| Paleozoic | Not differentiated. | | |

## Typical geologic Sections.

In order to appreciate the multiplicity of geologic formations and their history, both during and after deposition, attention is invited to the accompanying map and cross-sections in connection with the preceding enumeration. The entire sequence of formations given do not occur at the surface in any one of the profile sections, but the relation of one to another is plainly shown by the parallel profiles.

*PRESTON SECTION.*

This section is from Tishomingo, Chickasaw nation, southward to Sherman, Texas. It is typical of the western portion of the area, and the following beds are exposed·

| | | | |
|---|---|---|---|
| Pleistocene and recent | | Alluvium. | |
| | | Second bottom deposits. | |
| Upper Cretaceous | | Austin chalk. | |
| | | Eagle Ford shales. | |
| | | Lower Cross Timber (or Dakota) sands. | |
| Lower Cretaceous (Comanche series). | Washita division | Main Street limestone | Denison beds. |
| | | Paw Paw clays | Denison beds. |
| | | North Denison sands | Denison beds. |
| | | Marietta beds | Denison beds. |
| | | Fort Worth limestone. | |
| | | Duck Creek chalk | Preston beds. |
| | | Kiamitia clays | Preston beds. |
| | Fredericksburg division. | Goodland limestone. | |
| | | Walnut clays (*Exogyra texana* beds). | |
| | Trinity division | Sands representing consolidated Trinity division. | |
| Paleozoic | | Carboniferous shales and sandstones. | |
| | | Silurian. | |
| | | Granite. | |

*Trinity Sands.*—The base of the mountains in southern Indian Territory is everywhere marked by a narrow belt of excessively sandy soil covered with oak timber exactly similar to that of the western Cross Timbers of Texas. This is the outcrop of a formation of pack-sand identical in character with that of the Trinity and Paluxy sands of the Brazos section in Texas, except that the limestones, which there separate them, have thinned out in the country north of the Brazos. I was unable to decide whether this sandy strip represented either one or both of the sands of the Trinity division in Texas, and, to distinguish this Indian Territory phase of these basement sands from their differentiated character as found in Texas, I shall use the provisional name of Antlers sands. The Glen Rose limestones, so highly developed in Texas to the south and in Arkansas to the east, do not outcrop, so far as observed, in Indian Territory.

*Walnut Clays.*—At one point north of Marietta the typical Walnut clays (*Exogyra texana* beds) have a slight development below the Goodland limestone, but eastward of this point they are not exposed.

*Goodland Limestone.*—The Walnut clays are capped by a hard, pure white crystalline limestone to which the local name Goodland limestone

has been given. This limestone, by chemical induration, has at places assumed the hardness of marble, taking a handsome polish. This induration is superficial, however, for at other places away from the surface it is soft and pulverulent. The limestone occupies the bluff of a northward-facing escarpment from Emmet, Chickasaw Nation, eastward to Goodland, Choctaw Nation, and finally disappears in the flood-plain of Little river, five miles east of the Arkansas line. It also outcrops in Grayson county, Texas, about two miles south of the historic geologic locality of Old Preston, and forms the south bluff of Red river valley.

The Walnut clays and the Goodland limestone together represent the greatly attenuated northern beds of the Fredericksburg division, which has a constantly increasing thickness southward. The limestone is the northward continuation of two upper calcareous members of the Fredericksburg division (the Caprina limestone and Comanche peak chalk) south of the Brazos, but I shall continue to use the local name for this bed where it represents this consolidated phase.

The Goodland limestone contains the following characteristic Fredericksburg species: *Cyphosoma*, sp.; *Enallaster texanus*, Roemer; *Gryphæa navia*, Conrad (not of others); *Rostelaria*, sp.; *Cerithium bosquensis*, Shumard (i. e., *Chemnitzia occidentale*, Gabb), and *Sphenodiscus roemeri*, Cragin. The remarkable aberrant Chamidæ and Rudistæ so well developed in synchronous and deeper beds to the southward are missing.

*Beds of the Washita Division.*—Succeeding the Goodland limestone are the basal Kiamitia clays of the Washita division, forming a prairie region sloping away from the Goodland escarpment. These clays are succeeded in turn by the other members of the Washita division of the Comanche series, which are described more minutely on page 324. All these beds, with one exception, are calcareous and outcrop as prairies. The North Denison sands is a terrane of unconsolidated sands, and like the Trinity and Dakota its outcrop is invariably covered with timber.

*Lower Cross Timber (or Dakota) Sands.*—Capping the uppermost bed of the Washita division (the Main street limestone) unconformably, the Dakota sands constitute two intensely arenaceous and ferruginous belts of country, forming low timbered hills in that region. I have previously defined these beds as the Lower Cross Timber sands, while Doctors B. F. Shumard and C. A. White have correlated them with the Dakota.*

These sands are unconsolidated except in their basal portion, where

* The brothers Shumard made several publications on the region treated in this paper, but completely misinterpreted the stratigraphic sequences of the beds, and in some cases referred them to the Tertiary system. The Third Annual Report of the Geological Survey of Texas used Dr B. F. Shumard's terms of Red River group, originally applied to many beds, for this terrane. It is gratifying to note that Mr Taff abandons this untenable position in the second part of his report in the Fourth Annual, and besides gives most valuable details of the stratigraphy of the Dakota and Eagle Ford beds, which, with the Denison beds, in part constitute Shumard's old Red River group.

ferrugination has produced hard indurations of deep brown silicious hematite. This induration is superficial. It will be observed that these beds have three outcrops on the map. Two are small east-and-west strips; one south of Denison and the other thirty miles northward—five miles south of old fort Washita. The third is a great north-and-south belt west of them and extends from Red river southward to the Brazos.

The reasons for brief correlation of these beds with the Dakota by Shumard are good, so far as our imperfect knowledge of the poorly defined Dakota as a whole will allow. They are of the same lithologic character as the Dakota to the northward in Kansas, and in some of the indurated ironstones I collected the same dicotyledonous fossil plant previously noted by Shumard,* principally *Sterculea*, *Salix*, *Populus*, etcetera. I have had no time to undertake the critical study, except in a general way, of my collections or the paleontology of these beds, having deferred it until the study of the lower Cretaceous † is completed.

*Eagle Ford Shales.*—The Eagle Ford shales of my original section ‡ of the Texas Cretaceous appear lithologically modified along the line of our Denison profile between the south bank of Iron Ore creek at Cooks springs and at Sherman. The continuity of the entire section could not be made out, but I present it as far as I can safely interpret it.

At the base the beds consist of yellow arenaceous layers and clays, which grade up into dark blue shale similar in color to the Cretaceous shales of Colorado, and not of the marly white colors that distinguish the Comanche clays. In their middle and upper portion there are many blue calcareous concretions, septaria, with beautifully preserved fossils, while they terminate near the top with an arenaceous horizon abounding in fish remains, teeth and the unique *Ostrea bellaplicata* of Shumard. These clays which underlie prairie regions are undoubtedly Benton.

*Austin Chalk.*—The typical Austin chalk surmounts the Eagle Ford shales in the city of Sherman, and is of the same general character as has been previously described in its extent to the southward. The areal outcrop of the formation here forms the highest point of the whole

* Mr Taff has presented the only detailed stratigraphy of the Dakota and Eagle Ford beds in the region south of Denison to Waco along the south strip, and this portion of his report is a valuable contribution. He does not treat of their extension east of Denison, however.

† Am. Jour. Sci., April, 1887, pp. 288, 289.

‡ I have always drawn the line between the Eagle Ford and underlying Dakota at the yellow silicious band on the north bank of Iron Ore creek near Cooks springs, at the horizon of the association of *Cyprimera crassa*, Meek, not Cragin, and *Exogyra columbella*. Other species in the Commanche series are erroneously called by these names in the Texas reports. *Cyprimera crassa* of Cragin as used in the reports of the Texas survey is not *C. crassa* of Meek, and the latter only occurs in the Upper Cretaceous and not in the Comanche of Texas. Mr Taff announced in his first report the "first discovery" of *Exogyra columbella* in Texas in the beds of the Washita in central Texas, although it had been previously reported from this Eagle Ford horizon (see the Texas section of the North American Cretaceous, Am. Jour. Sci., October, 1887, p. 297). In his second report he apparently abandons this reference, and properly mentions it in the Eagle Ford horizon,

region and a kind of promontory, the escarpment of which extends southward to Austin.

The foregoing are all the deposits laid down at marine baselevel in the vicinity of the Preston section. Fluviatile deposits are highly developed in the valley of Red river, but more will be said of them later.

*Review of the Section topographically.*—Let us now review the topographic expression of the members of this section. By reference to the serrated profile it will be seen that it is broken north and south of Denison by two faults running parallel with the strike—one, the Preston fault, with a downthrow to the northward by which the Dakota is brought down to the Trinity, and the other, the Cooks spring fault of Taff, with a downthrow to the south by which the Eagle Ford is brought down to the Dakota. These fault systems play a most important part in the production of the topographic features of the Denison section, for by them the normal outcrops of these rocks are doubled, each member in the section from Red river to Sherman, but not including the Austin chalk at Sherman, being duplicated on the downthrow of the fault north of the river. It will also be seen that each of these rock sheets has its peculiar topographic expression. The outcrop is to the northward or toward the mountains and the general dip to the southward. Where the strata are composed of indurated material—such as the Goodland limestone, the Duck creek chalk, the Fort Worth limestone and the Main street limestone—escarpments of stratification are produced, the summits of which, to the next harder member, are usually composed of the intervening softer, less indurated beds, such as the Walnut clays, Kiamitia clays, Marietta clays, Paw Paw clays, Eagle Ford shales, and the Trinity sands. The conspicuousness and extent of these east-and-west escarpments is proportionate to the induration and resistance to weathering of the limestone beds. The three sandy terranes—the Trinity, the North Denison, and the Dakota—outcrop in undulating hilly areas. The hardest and most persistent of the limestone scarp-making members is the Goodland limestone, and its escarpments form one of the most conspicuous features in southern Indian Territory, extending east and west from North Marietta to the near eastern edge of the Choctaw nation. The valley occupied by the Trinity sands and lying between it and the mountains is coëxtensive with this escarpment. Southward through Texas the Goodland limestone differentiates into the Comanche peak facies; that is, into harder upper beds of Caprina limestone and softer basal members of Comanche peak chalk and Walnut clays—and its scarp-making properties increase until they constitute most of the mural buttes and drainage divides of the great central Texas region, as shown in my previous papers.

The Fort Worth, Duck creek and Main street limestones of the Washita division being softer than the Goodland, their interior-facing escarpments of stratification are less pronounced, but nevertheless traceable throughout their extent until these formations are lost in the faulting south of the Brazos. The Austin chalk forms an escarpment of stratification even higher, but less angular than the Goodland limestone. It does not outcrop eastward down the valley of Red river as do the others.

*PARIS SECTION.*

One hundred miles east of Denison a parallel section will show differentiation from the features of the Preston section. The Trinity valley, the Goodland limestone and the Washita dip plains are seen in the Choctaw nation as in the Chickasaw. The Dakota (Cross Timber) hills have disappeared, however, and this formation occupies the lowest bluff of the low river valley. The Preston and the Cook springs fault have passed southeastward off our map and do not appear along this line. The Lower Cretaceous no longer outcrops south of Red river, and the Austin chalk has disappeared entirely by faulting, while the latter beds of the Upper Cretaceous or Glauconitic division, unrepresented in the Denison profile, appear in the southern portions of Fannin, Lamar and Red River counties. They, with the Eagle Ford, constitute fertile black prairies* exceedingly difficult to differentiate from one another, but nevertheless distinguishable, the latter occurring mostly north of the transcontinental branch of the Texas Pacific railroad running from Texarkana through Sherman to Whitesboro'. The structural dip plains, so conspicuous in northern Grayson county, no longer occur on the Texas side of Red river, and are limited to the narrowing Lower Cretaceous prairies near Goodland,† while on the Texas side the contour is a low arc forming the divide of the Red and the Sulphur river.

Here the fluviatile deposits have increased in width to many miles along Red river, which here flows through Dakota. From Arthurs bluff I have made three collections of the Dakota flora, which are now in Columbia college, the National Museum and in the state capitol of Texas.

The members of the Glauconitic division in this section throw great light on the Upper Cretaceous history, showing that the beds I have

* The topography of the black prairies of Texas and their extent are mapped and described in my report On the Occurrence of Underground Waters etc., 52d Cong., 1st sess., Sen. Doc. 41, Washington, 1893, 2d edition.

† The Goodland prairies on this profile are the original plains of the Kiamishi, from which Dr Pitcher collected the famous *Gryphœa pitcheri* of Morton in 1827, the first to be described of what are now known to be Comanche fossils, and which has been almost inextricably confused with others, the true characters and specific definition of which I shall soon present in another paper.

previously described in southwest Arkansas extend into Texas. South of Paris, as in Arkansas, this division consists of three conspicuous members. The base is a pure white chalk rock, the White Cliffs chalk of my Arkansas section, but called the Anona chalk in Texas, accompanied by beds of glauconitic chalk or chalky glauconite, which in the field we have designated *cement rock*.* Above this are glauconitic marls, called Brownstown marls in Arkansas and Kickapoo marls in Texas, which bear a growth of hardwood,† including Bois d'Arc. Finally come the Glauconitic sands, with the fauna of the greensand marls of New Jersey, but generally more arenaceous. It is not known what has become of the Austin chalk in this section, but my hypothesis, backed by some evidence, is that to the southward it has been faulted down. The Anona (White Cliffs) chalk is an entirely distinct and higher bed, for it is underlain by the Taylor (*Exogyra ponderosa*) marls which overlie the Austin chalk, and on our next profile we will see that the Austin chalk reappears in its normal position to the eastward in Arkansas. The Anona chalk is stratigraphically the same as the White Cliffs chalk ‡ of my Arkansas section, and is analogous in position to the upper white chalk of England, while the lower Austin chalk is analogous to that of the lower chalk of that country. In chemical analysis they also resemble, the upper having about 98 per cent. of lime, the lower averaging about 89. This lithologic coincidence is worthy of note.

### *ULTIMA THULE SECTION.*

This runs south from the Ouachita mountain along the Choctaw-Arkansas boundary.

The Trinity still rests on the upturned Paleozoic, but the Cretaceous formation ceases to predominate, and the estuarine and Pleistocene fluviatile deposits now constitute the chief surface features. The Goodland limestone ceases to form the prairie divides and descends into the lowest flood plain of Little river, covered by later deposits, and does not appear again to the eastward. The Washita beds form the higher bluffs of the south bank of the stream, and likewise dip beneath its level a few miles east of the profile. The Dakota also disappears still eastward, at Morris ferry.

The divides along this profile are flat plains—veritable mesas—capped by one of the greatest deposits of stratified gravel and bowlders in our country, the probable continuation of the late Neocene deposit so ably

* This consists of a chalky matrix specked with minute grains of glauconite.

† This is the only marly terrane in the entire range of Cretaceous formations in Texas which is covered by arborescent vegetation.

‡ In November, 1892, the writer found a single specimen resembling *Ananchytes ovata* in this chalk at White Cliffs. It was impossible for Professor W. B. Clark to insert it in his publication on Mesozoic Echinodermata, as it had gone to press.

described by McGee as the Appomattox or Lafayette formation, and which is the Plateau gravel of my Arkansas report. This caps the Little and Red river divide and that of Red and Sulphur river, and is surrounded on all sides by the later second bottom valleys of the drainage system.

The recent and Pleistocene valleys of Red river, or "bottoms" and "second bottoms," as they are called, have widened to great proportions along this section, and their phenomena alone would occupy many pages of description. They extend from twelve to fifteen miles on each side of the river, and the river itself begins to assume that serpentine meandering which characterizes the retarded drainage of the low Mississippi embayment. The baselevel deposits of this region are: (*a*) Present deposition at times of overflow; (*b*) ancient or second bottom deposits, occurring about 100 feet and higher above the level of present high water; (*c*) swampy lacustral or marsh deposits upon the higher slopes making the prairie at New Boston, Prairie d'Ane, etcetera; (*d*) the older Plateau gravel constituting the divides.

Beneath this veil of post-Tertiary estuarine deposits two views of the underlying floor of Upper Cretaceous marine sediments are obtained through erosion. In Little River county, Arkansas, the Austin chalk is exposed at Rocky Comfort—so named because it is probably the only dry spot in that county of overflow and backwater. About fifteen miles southward, in Bowie county, Texas, at the Freise place, the Greensand beds of the Glauconitic division are exposed.

Near the summit of the divide of Sulphur and Red river, close by the old abandoned town of Boston, the typical laminated clays and sands of the Eocene-Tertiary appear beneath the Plateau gravel, which forms the cap, and are exposed from thence southward in the Sulphur river slopes and bottoms.

### *ANTOINE SECTION.*

This is in Arkansas, 60 miles east of the Choctaw line. The Trinity valley and sand still follow the mountain foot. The upper limestone or Glen Rose member of the Trinity, which has been missing westward from the Trinity river in Texas, reappears in a small area, but the Fredericksburg, Washita, Dakota and Austin beds have been completely overlapped by later deposits. The Glauconitic outcrops in patches beneath the Eocene overlap, and the Plateau gravel still spreads its mantle over all the uplands except where cut through by the ever increasing second bottoms. The Eocene begins to appear north of Little river from Nashville to Arkadelphia, approaching nearer and nearer the ancient mountain shore. A few miles east of this section, near Arkadelphia, the Glauconitic completely overlaps the Trinity and abuts against the upturned mountains.

*ROCKPORT SECTION.*

Still eastward the Glauconitic is overlapped, and we find the Eocene covering all, the Tertiary resting directly upon the upturned mountain floor at old Rockport, near Malvern.

## Extent and topographic Expression of the Terranes.

The basement Trinity sands indicate the most important epoch in all post-Paleozoic history, and, like the movement at the close of the Carboniferous, may be said to be one of the grand criterial events of our whole geologic history. It represents the baseleveling and invasion of the Texas-Mexican region by the Atlantic, and is the most marked unconformity in the Texas region. The sands are deposited in southern Indian Territory directly upon the previously baseleveled floor of the

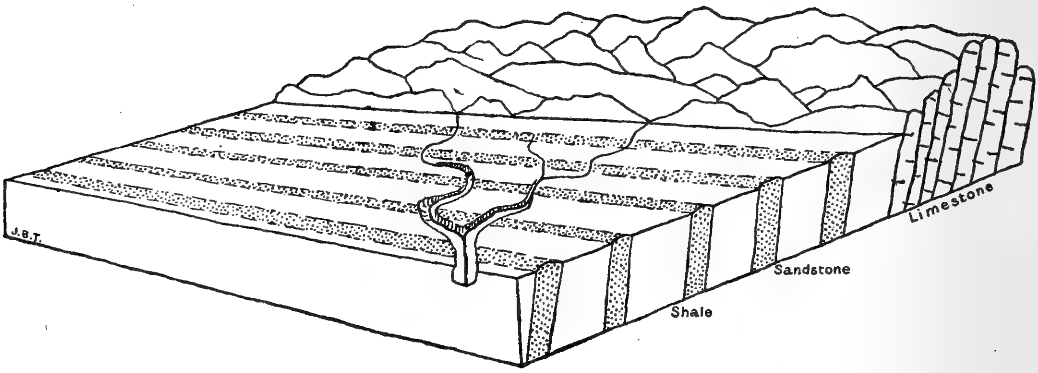



Figure 1.—*Vertical Structure of Paleozoic rocks underlying Prairie west of Ardmore.*

Paleozoic rocks of the southern border of the Ouachita mountain system, as shown in the Arkansas sections. The planing of these Paleozoic folds, upon which the Trinity sands are deposited, took place largely by land erosion before their deposition, for in the Chickasaw nation, west of Ardmore, similar baseleveling is now going on, and the level prairie is composed of the same vertical, planed-off Paleozoic structure as that buried beneath the Trinity sands in Arkansas, as shown in the profiles.

These sands in Indian Territory and Arkansas now outcrop in a denuded valley of stratification, as distinguished from a normal drainage valley; that is, a valley is formed by the southward receding from the mountains of the escarpment of the Goodland limestone of the Fredericksburg division. This valley results from the interception of the headwater ramifications of the secondary branches of the main drainage channels.

West of Marietta, Chickasaw nation, the strike of the whole Cretaceous system turns directly southward through Texas. The underlying floor

rocks change in various places from Carboniferous to Silurian or to Red beds, in accordance with the diverse areal geology of the land during the time of their deposition; but these rocks were entirely buried in central Texas beneath the Cretaceous, whose western shoreline extended to the nucleal Rocky mountain region.

To the southward, in the vicinity of the Brazos, the Trinity limestone terrane (the Glen Rose beds) begins to outcrop (see vertical sections on plate 13), separating the sands into an overlying and underlying formation. These limestones increase in thickness southward until they are nearly 500 feet at the Colorado river. The reappearance of this intercalation of the limestone members of the Glen Rose beds in a small area in Arkansas near Murfreesboro is peculiar.

The Goodland limestone everywhere west of Arkansas forms an escarpment overlooking interiorward the lower Trinity division. South of the Brazos it thickens into the tripartite formations of the Fredericksburg division, but its scarps of indurated limestone continue to be the formative factor in determining the topography of the Texas region. As it is the stratum of greatest resistance, it expresses itself in escarpments of dip-plains, mesas and buttes.

The Kiamitia clays, which are a type of the marly clay members of the Comanche series, are expressed in the topography as blackland prairies, limited coastward by the scarp lines of the harder and more resisting Duck Creek and Fort Worth beds.

The Dakota or Lower Cross Timber sands participates in this east-and-west strike throughout Indian Territory and northern Texas and the southern deflection through the latter state. Its narrow outcrop surmounts the prairies as low, rounded, timbered iron ore hills. Its strike is split longitudinally into two belts by the faulting described. The half north of Red river thus split off caps the hills south of fort Washita and extends eastward to the Missouri, Kansas and Texas railroad. The southern half of the ribbon of outcrop constitutes the hills south of Denison. Their line of eastward strike is cut into by Red river near the eastern border of Grayson county, and that stream virtually flows in these beds as far east as Pine bluff at the northeast corner of Lamar county, where the river first deflects northward upon the Washita division and then southward into later deposits. Near Pine bluff the Dakota, with its east-and-west strike, crosses into Indian Territory and finally disappears under the bed of Little river at Morris ferry, which is about 10 miles east of the Choctaw line. This formation was undoubtedly laid down at marine level, and is not of lacustral origin, as argued in the correlation papers of the United States Geological Survey,* for I found at Pine bluff Ammonitidæ

* Bull. U. S. Geol. Survey, no. 82, pp. 122 et seq.

and other marine mullusca in association with lignite and the characteristic flora. As a whole, it records the littoral débris accompanying the great oceanic invasion of the Great Plains region in Upper Cretaceous time. It is important to note also that the Dakota is a glauconitic formation, and I believe this is the first time that fact has been clearly announced. The intense ferrugination is derived from the oxidation of this glauconite, as clearly shown at Pine bluff, and the glauconite bed which outcrops in clearest purity at Morris ferry of Little river in Arkansas * belongs to the Dakota.

The Eagle Ford shales, or Benton outcrop, is along the strip of land immediately south of the Dakota, and usually follows the south side of the Red river valley. The variations of outcrop are shown upon the map. They have no determinable outcrop in Indian Territory that is separable from the Dakota, except at Carriage point prairie, north of Denison.

The outcrop of the Austin chalk does not deflect eastward down Red river on the Texas side, but it has apparently been cut off by the Cooks springs fault, and the area which should be its normal outcrop is occupied by the higher beds of the Glauconitic division, which constitutes all the Cretaceous outcrops of the Red river counties south of the transcontinental branch of the Texas Pacific railroad, east of Grayson county.

The areal development of the Glauconitic division in Texas is almost entirely confined to the area embraced upon our map. As its beds to the southward are more and more overlapped by the Tertiaries, they only occur in a few isolated and exceptional localities. Its exposures in Fannin and in Lamar county are best explained upon the plausible hypothesis that its outcrops are on the "uplift" block in the angle of the two great fault systems—the Balcones and Red river.

There can be little doubt but that during the Pleistocene and late Tertiary time the Sulphur and the Red river valley and those of the northward lateral drainage of the latter were the scene of oscillation, accompanying baseleveling and estuarine deposition. The ancient alluvial deposits certainly belong to several well defined epochs of baseleveling and erosion somewhat similar to yet more complicated than those of the Potomac region. The Plateau gravel, which is the oldest of these, was laid down at a time when sealevel was 500 feet lower than today, and the interior margins and continuity of this formation has been so destroyed by the development of subsequent drainage upon and across it that no detailed hypothesis of its origin can be given until more minutely studied. The sheet as a whole represents the connected deposition of many streams which reached baselevel near the line of its present

* See Neozoic Geology of Southwest Arkansas, p. 89.

interior strike throughout Arkansas, Indian Territory and Texas, and it belongs to the phenomena discussed by McGee under the head of "The Lafayette Formation."* The position and history of Red river during this epoch have not been determined. All the terraces, benches and wide bottom lands lying above the present Red river and the wide flood plains are called "second bottoms." It would be just as appropriate to speak of the third, fourth and fifth bottoms in some cases, for the so-called bottom phenomena do not represent a single epoch of baseleveling and deposition, and for the present we class them together and lay them aside for future investigation to interpret.

These alluvial deposits and their wide eroded valleys occupy a large proportion of the country and in some instances extend fifteen miles from the river. They are not only developed in Red river, but they especially characterize all the northward laterals flowing down from the Ouachita mountains. Together with the timbered Trinity valley they surround the quadrangular gravel plateaus of Arkansas and Kiamitia prairies with belts of lower timbered valleys.

The second bottom formations of Red river and of Sulphur fork unite in the easternmost Texas county and send wide prolongations up their respective streams. As we go westward the Cretaceous prairies begin to appear in the angle between them, gradually increasing in proportionate area to the westward as the second bottom phenomena diminish.

## Fault Systems and their Influence on Topography and areal Geology.

The northwest and southeast faulting mentioned has greatly influenced the areal distribution of the formations and especially in the eastern portion where the rocks are mostly of an unconsolidated character. I have previously described † a great line of faulting with a northeast-and-southwest strike and an eastern downthrow known as the Balcones system, which extends from the Rio Grande northeastward via San Antonio, Austin, Belton and Dallas toward Red river, and probably crosses into Arkansas. It would be represented on the east border of the map west of where the Arkansas-Choctaw line touches Red river. This system of faults, the writer believes, crosses the area under discussion through the unconsolidated beds, but it is difficult to locate them where the consolidated rocks are unexposed.

The Red river system of faults, however, strike at right angles to the Balcones system and apparently crosses it in the central Red river

* 12th Annual Report U. S. Geological Survey.

† Texas Section of American Cretaceous: Am. Jour. Sci., October, 1887.

counties, thus adding to the difficulty of differentiating the unconsolidated clay formations in a prairie country covered by a thick residual soil, but wherever the chalky rocks occur they again become evident. As we go westward, however, into Grayson county, where the more consolidated beds enter into the structure, the faults become tangible and play a potential part in the topographic features, as explained on a previous page. Still north in the Chickasaw Nation, near Carriage point, intense faulting with the same northwest strike can be seen in the Eagle Ford prairies.

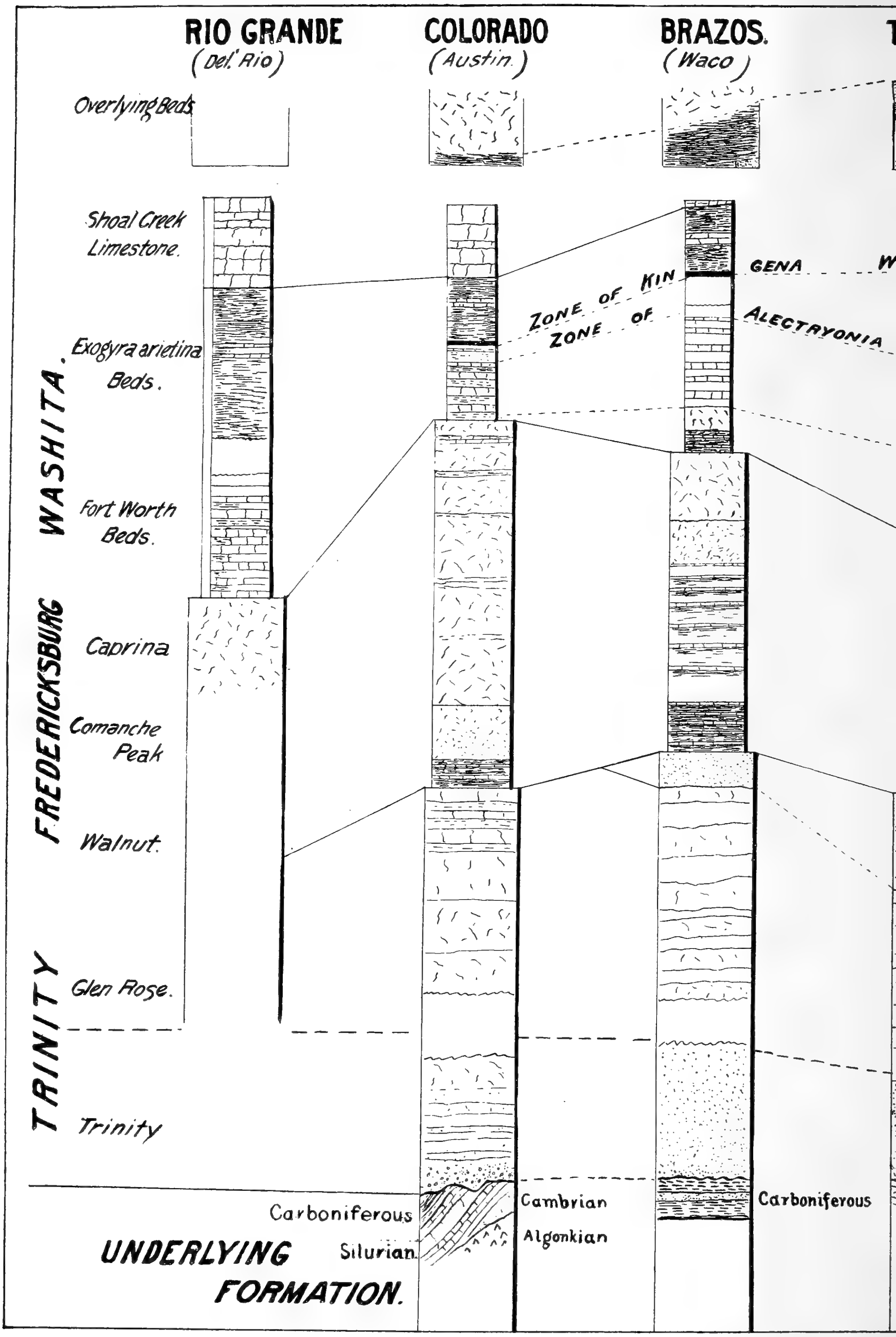
Mr Taff has recently described an important fault (the Cooks springs fault) south of Red river and parallel to the Preston fault, in which, however, the downthrow is reversed, being to the southwestward.

Near Roxton and Ladonia, in the southeast corner of Lamar county, the northwest and southeast faults (presumably of the Red river system) are visible.

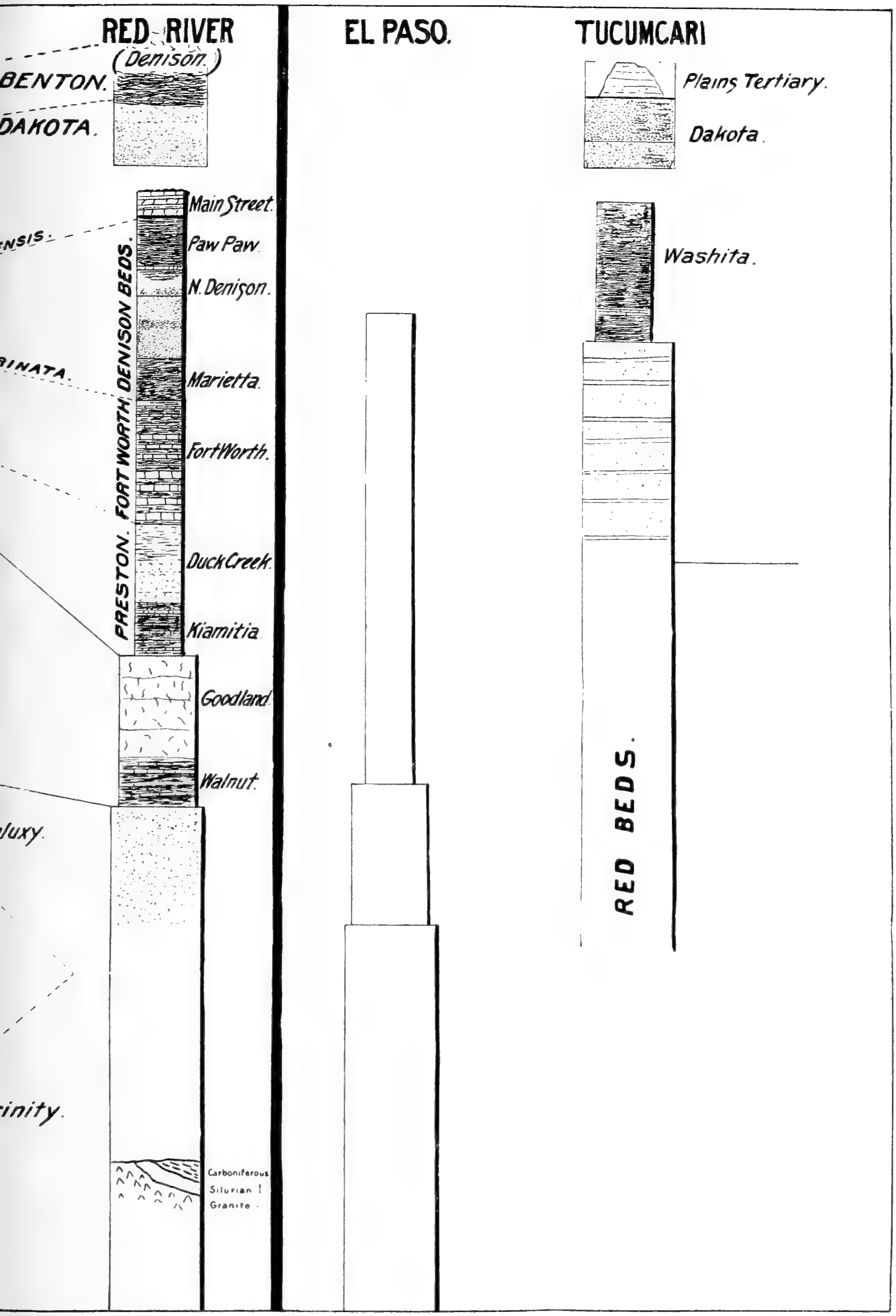
Between Clarksville and Anona, in Red River county, the northeast and southwest faulting is seen in the upper chalk of the Glauconitic division. In the line of the great Balcones system it will be seen by projecting the strike of these two fault systems upon the map of Texas that the small county of Rockwell lies very near to where they cross each other. This county takes its name from a peculiar sandstone dike, previously described, which projects through the clays near the base of the Glauconitic division. The southeastern or Red river system of faulting will explain the remarkable change of strike which takes place at the west end of our map. In the Chickasaw nation and northwest Grayson county a kind of wedge is formed by the opposite downthrows of the Preston and the Cooks springs fault, which projects northwestward into an angular ridge. Probably several faults of this whole system have not been exactly located, for all of the Chickasaw nation north of Red river has certainly dropped far below the level of the opposite country in Grayson county, Texas. The age of this faulting is not clear, but it could not have been much earlier than the time of the Plateau gravel, probably during the Neocene.

## Variation of Sedimentation away from the Ouachita Shoreline.

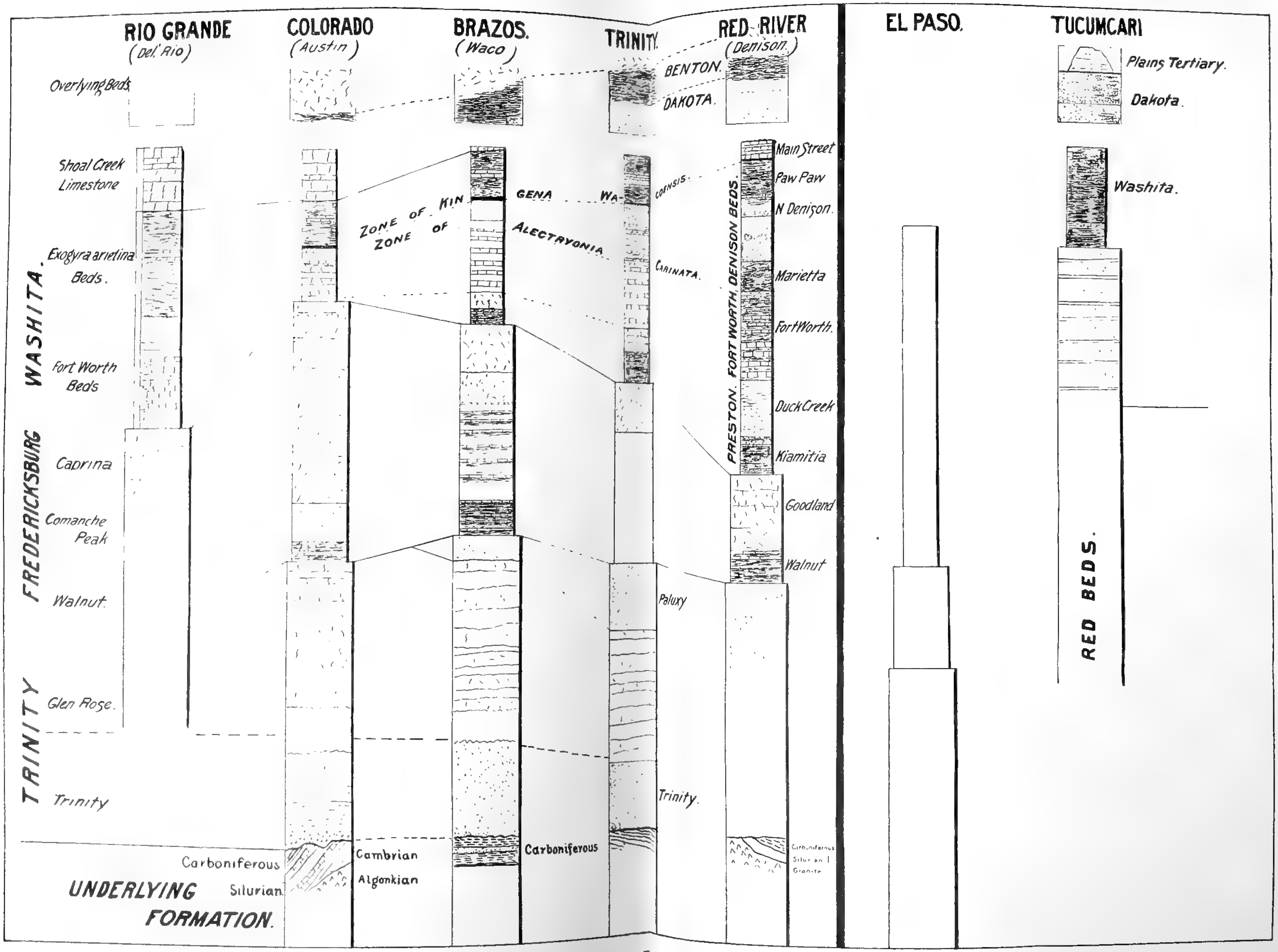
The various beds of the whole section do not all strike away from the Ouachita shoreline in the same direction over the Texas region. The second bottoming occurs in all the rivers southward at least as far as the Colorado, probably beyond, and extends farther inland in places than the Plateau gravel. The Plateau gravel shoreline, as I have previously published, continues to occupy the divides as far southwest as Austin,




VARIATION OF THE COMANCHE SERIES BETW




ACHITA AND TRANS-PECOS MOUNTAINS.




VARIATION OF THE COMANCHE SERIES BETWEEN THE OUACHITA AND TRANS-PECOS MOUNTAINS.

where it reaches the foot of the escarpment of the Balcones fault, against which it was deposited, and follows it from thence indefinitely southwestward toward the Rio Grande. The Eocene strikes southward along the line which I have previously indicated upon the maps, but at no place south of Malvern do I know that the denuded outcrop now touches the original shore as far inland as it formerly extended, and one of the great unstudied problems in Texas is the interpretation of this former interior extent of the Eocene beds.

The beds of the Glauconitic division strike more southward than do those of the Eocene from their last outcrop in northeastern Texas, and are completely overlapped by the latter, except in the Red river counties. Far coastward in the Eocene area—in Anderson, Smith and other counties of Texas, and also in Louisiana, where the Tertiary has been eroded away, these beds are revealed occasionally, as shown by Hilgard, Johnson and Lerch, in small spots, which are sometimes spoken of as "Cretaceous islands," In fact, the Glauconitic beds of Arkansas are all inliers in the Tertiary area.* These outcrops are sufficient to demonstrate that the Glauconitic beds underlie a large part of the east Texas Tertiary surface sheets.

These profiles have an important bearing upon the question frequently asked the writer—Why has the great calcareous portion of the Lower Cretaceous so well represented in the Texas region no representation in the North Atlantic or New Jersey area? The sedimentary conditions of the last named region do occur in Arkansas and may be traced southward to Arkadelphia. Stated briefly, they consist of numerous thin, unindurated, mostly ferruginous terranes of basal Lower Cretaceous (Potomac), Upper Cretaceous (Glauconitic), Eocene and later littoral deposits. In the profiles given it will be seen that the deeper water or limestone beds appear to the westward in greater proportion as the land stripping has progressed, and are concealed eastward by the successive overlapping more and more toward the interior of the newer and differently striking shore deposits. The off-shore limestone deposits of the Cretaceous, if they exist in the New Jersey area, would only occur in that portion of the crust now beneath the ocean. In the Arkansas region the area of littoral deposition was constantly repeated, owing to the mountainous barrier. In Texas south of Red river these shorelines had wider room for sweeping and differential overlapping.

The beds of the Lower Cretaceous have a slightly different strike away from the Ouachita shoreline than those of the Upper Cretaceous. The individual beds also vary in like composition and sedimental characters away from the Ouachita shore.

*This fact was not appreciated by the writer at the time when his Arkansas report was written.

*WASHITA DIVISION OF THE COMANCHE SERIES.*

*Relation to other Divisions.*—As an example of this differentiation away from this shoreline let us take the beds of the Washita division of the Comanche series. The Washita division is the uppermost of the three grand divisions of the Comanche series, and is essentially composed of the shallowing beds which followed the culmination of the great subsidence during the Comanche time, as represented in the chalkier beds of the Fredericksburg division. The term "division," which has the equivalency of the word "group" as used by Dr White for the Upper Cretaceous, was first applied by me * to the beds of the Comanche series for the purpose of conveniently grouping them until their subdivisions could be more minutely studied and classified. Fossils from beds which are now recognized as the upper portion of the Comanche series had been originally collected in the vicinity of fort Washita, in Indian Territory and in northern Texas by Dr G. G. Shumard † and Professor Jules Marcou, ‡ and Dr B. F. Shumard had named certain of these beds the Washita limestone;§ hence the upper division was called the Washita division, and in a similar manner, from the fact that the fossils described by Dr Roemer from Fredericksburg, Texas, and by Dr Shumard from Comanche peak were discovered to belong to beds of the middle division, the lower part of the series has been called the Fredericksburg or Comanche peak division.

In my earlier writings the Trinity division, including the Trinity sands and the great development of alternating lime beds of the Glen Rose, was not separated from the Fredericksburg division, nor had these lower beds been recognized or intimated by previous writers. A fuller definition of the Trinity division has recently been published by the writer.||

The necessity for this arrangement into divisions will be furthermore appreciated by the accompanying table, which shows the progressive evolution of knowledge concerning the Cretaceous formations of Texas, and is my final classification of their succession and nomenclature. Some of the beds may be subdivided again in the future.

The Fredericksburg culminates everywhere throughout its extent in very chalky limestones which, in central Texas, have been denominated Caprina limestone and the Comanche peak beds by Shumard;¶ and its northern attenuated portion in Indian Territory and northern Texas

* Am. Jour. Sci., April, 1887.

† Exploration of the Red river of Louisiana, etc, 1852.

‡ Geology of North America and other works.

§ Trans. St. Louis Acad. Sci., vol. i, 1860, p. 586.

|| Proc. of the Biological Soc. of Washington, June, 1893.

¶ Trans. St. Louis Acad. of Sci., 1860.

*Progressive Development of Knowledge of the Texas Cretaceous.*

(Numbers and parentheses by R. T. Hill.)

| Dr Ferdinand Roemer, 1846. | Dr B. F. Shumard's Section of 1860. | Professor Jules Marcou, 1861. | Robert T. Hill, 1886–'93. |
|---|---|---|---|
| Made no section or nomenclature, but mentions in the sequences given what are known to be the following beds: | *Upper Cretaceous (mostly Lower).* | (Criticism of Shumard's section, and rearrangement.) | *Upper Cretaceous.* |
| | 6. Caprina limestone. | | Glauconitic division:<br>18. Washington.......................<br>17. Brownstown.......................<br>16. White Cliffs.......................<br>15. *Exogyra ponderosa* (Taylor) marls.......................<br>} Montana division. |
| *Cretaceous of the Highlands.* | 4. } 5. } Comanche Peak group. | *Senonian (Upper Cretaceous).* | |
| 6. } 5. } Chalk marls and limestones of Fredericksburg (Caprina and Comanche Peak). | 14. Austin limestone. | 14. Austin limestone. | Colorado division:<br>14. Austin chalk.<br>13. Eagle Ford shales. |
| | 13. Fish bed. | Fish bed in sandstone. | |
| 4. Limestone flags with *Exogyra texana* (Walnut beds). | 10. Indurated blue marl (*E arietina*). | 13. Blue marl with *I. problematicus.* | Dakota division:<br>12. Lower Cross Timber sands. |
| | 9. Washita limestone. | | |
| 2. Chalks with *Orbitulina texana* and *Natica prægrandis* (Glen Rose). | 12. Blue marl. | *Middle Cretaceous, or Greensand and Turonian.* | *Lower Cretaceous.* |
| | 2. Caprotina limestone. | | Washita division:<br>At Austin. At Denison. |
| 10. Yellow clays with *Exogyra arietina.* | | 13. Marly clay or Red River group. | 11. Shoal Creek limestone. |
| 9. White limestone with *O. carinata* (Washita or Fort Worth). | *Lower Cretaceous (all Upper).* | 6. Caprina limestone. | 10. { *E. arietina* beds.......... Denison beds. { Main street. Paw Paw. North Denison. Marietta. |
| 6. Dolomitic limestone with *Requienia texana* (Caprina). | 12. Arenaceous group. | 4. } 5. } Comanche Peak group. | |
| | 13. Fish bed. | Superior part with *E. texana.* | 9. Fort Worth limestones.<br>Preston beds. { 8 Duck Creek chalk. 7. Kiamitia clays. |
| 6. Yellow limestone with Caprina (Caprina). | 13. Marly clay or Red River group. | 10. *Exogyra arietina* marl. | |
| *Cretaceous at Foot of Highlands.* | To which may be added later discoveries of— | *Lower Cretaceous, or Aptien and Neocomian.* | Fredericksburg division:<br>6. Caprina limestone; 6*b*. Austin marble; 6*a*. Flags.<br>5. Comanche peak chalk.<br>4. Walnut clays (*Exogyra texana* beds). |
| 15. Yellow marls with *E. ponderosa.* | | 9. Washita limestone, comprising superior part of Comanche Peak group with *G. pitcheri.* | Trinity division:<br>3. Paluxy sands.<br>2. Glen Rose beds.<br>1. Trinity sands. |
| 14. White limestone (with Austin chalk fauna). | 16. Ripley. | | |
| 13. Beds with fish teeth (Eagle Ford). | 12. Dakota. | 2. Caprotina limestone. | |

has been called the Goodland limestone by the writer. The limestones represent the deepest ocean sedimentation of the Comanche sub-epoch and the culmination of the subsidence during this time. They are overlain by laminated calcareous clays and alternations of stratified limestones, indicating that it was followed by shallowing conditions which continue upward to the top of the Washita division. These shallowing beds (the Kiamitia clays) overlying the Caprina limestone constitute the beginning of the Washita division.*

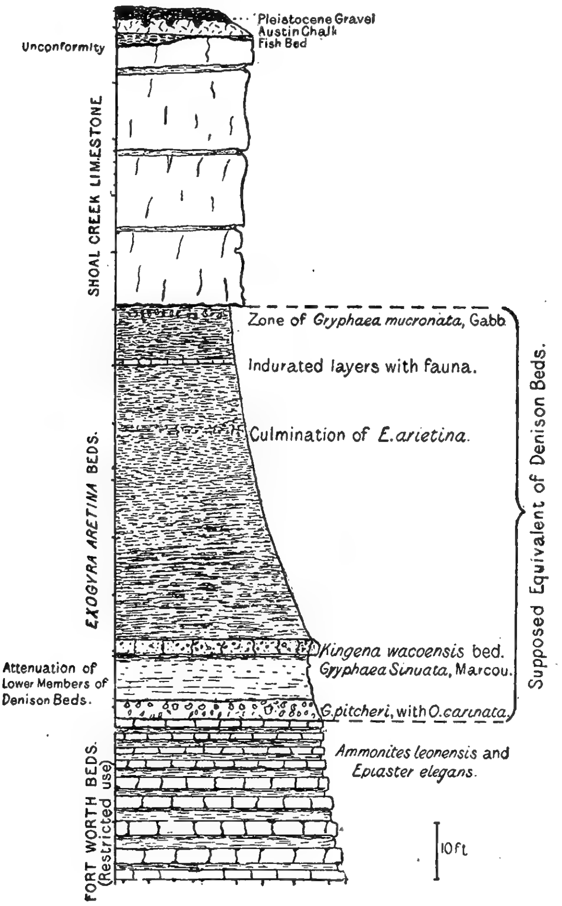



FIGURE 2.—*Structural Detail of the Washita Division at Austin, Texas.*

*Extent of the Washita.*—The extent of the beds of the Washita division north of Red river is shown upon the map. They commence exactly upon the boundary line of Choctaw nation and Arkansas, where Little river crosses the line. Two or three miles westward they occur as small spots of prairie in that densely forested region. These prairies of the Washita increase in area to the westward in southern Indian Territory until, north of Denison and Gainesville, Texas, they are the prevailing topographic feature. They then turn southward through Texas and extend to the San Gabriel, near the Colorado, constituting a large part of the prairie regions (the Fort Worth prairie) † of Cook, Denton, Wise Tarrant, Johnson, Bosque and Williamson counties. Southwestward, from the San Gabriel to the trans-Pecos mountains, the Washita beds do not constitute extensive areal outcrops owing to the great Balcones fault, which has cut them off

* In my preliminary annotated check-list of the Cretaceous invertebrate fossils of Texas I included the upper Caprotina limestone beds of the Austin section in the Washita division, but am convinced, after fuller study of these beds, that they more properly belong to the Caprina limestones and should be placed in the Fredericksburg division.

† Described in various earlier papers and amplified in my Report on Occurrence of Underground Waters, et cetera.

in that region. They appear in the Cordilleran region of trans-Pecos, Texas, and Mexico, as I have previously shown.

###### *COMPARISON OF THE AUSTIN AND DENISON SECTIONS.*

*Austin Section.*—In order to understand the variation of the Washita division seven typical sections, at widely distributed localities, are shown upon plate 13. As a basis of comparison with the Red river section there may be taken the Austin section, which is as follows:

| | | |
|---|---|---|
| Washita division | Shoal creek limestone. | |
| | *Exogyra arietina* beds. | |
| | Fort Worth limestone (old usage) | *Kingena wacoensis* bed. |
| | | *Gryphæa pitcheri* bed. |
| | | Fort Worth limestone proper. |

Here the beds of the Washita division constitute the three simple, conspicuous lithologic and paleontologic members; the lowest of them are alternations of slightly arenaceous limestones and chalky, laminated marls occurring in alternations and marked by a conspicuous molluscan fauna, to be enumerated later. Succeeding this lower limestone group is a great bed of unctuous green clay some 80 feet in thickness. This clay is in turn succeeded by a peculiar limestone, to which I have given the name Shoal creek limestone.

Shoal Creek Limestone.—This has its characteristic exposure, north of the Colorado, in the beautiful scarps of Shoal creek, in the city of Austin and in the bluffs on the south side of the river, where Bouldins creek enters the valley, at the crossing of the International railroad and the Oatmanville road. It forms precipitous cliffs, with toppling abutments, owing to its jointed structure and the undermining of the clays beneath, and is the principal scenic feature of Pease park in Austin.

Its outcrop is whitish yellow, with blotches of pale pink, as if it had been subjected to fire, and is much darker in exterior color than the other limestone strata of the Colorado section. In places it is very hard, but of varying texture; sometimes soft and efflorescent in spots, the rocks decaying into a soft, pulverulent material with slightly saline taste.

The red and pink blotches in this limestone are peculiar, and have given to it the local name of "burnt limestone." The writer once suspected that these spots were derived from the oxidation of intrusive or interbedded igneous material, like that found in certain portions of the adjacent Austin chalk;* but recent microscopic study has revealed the fact that the limestone is made up largely of foraminifera, filled and coated with a mineral which in all probability is glauconite, but in such small quantities that its oxidation only results in faint discoloration.

* Pilot Knob—A Marine Cretaceous Volcano: American Geologist, November, 1890, and Preliminary Check-List of Invertebrate Cretaceous Fossils, pp. xxiii, xxiv.

Exteriorly the stone looks very unpropitious for foraminiferal remains, but, so far as examined, it is more largely composed of them than any rock I have seen in the whole series. It is an altered chalk. In one thin slice I have recognized definitely *Rotalia*, *Textularia* and fragments of three or four more genera of foraminifera.

The outcrop of this formation is proportionately very limited, being better displayed at Austin than at any other locality where I have seen it. North of the Colorado it disappears by faulting until the San Gabriel is reached, near Round Rock, in Williamson county. It outcrops northward, according to Taff, at various points, constantly thinning until it finally disappears near Bosqueville, McLennan county, "where it is only two feet thick." North of the Brazos it has disappeared entirely, and its place in the columnar section is taken by the Dakota (Lower Cross Timber) beds, which do not occur south of the Brazos, but thicken northward from that stream, just as the Shoal creek limestone thickens southward.

The Third Annual Report of the Texas Geological Survey definitely stated that this bed does not appear north of the Brazos;* but in the Fourth Annual Report an entirely different bed,† the Main street limestone of this paper, north of the Brazos, has been called the Shoal creek (Vola) limestone, thereby adding confusion to the subject. A careful perusal and comparison of the two Texas reports will show that no paleontologic and stratigraphic proof is offered in the last paper mentioned for extending the Shoal creek limestone north of the Colorado. Neither is there any justification for placing the Shoal creek (Vola) limestone in the Kemp section of trans-Pecos,‡ Texas. It has been noted southward of Austin by the Texas Survey.

The Shoal creek limestone rests abruptly, without gradation, upon the *Exogyra arietina* clays wherever I have observed it. At Austin it is surmounted unconformably by the Fish beds—a greatly attenuated southern extension of a persistent horizon of the upper part of the Eagle Ford shales—and at one place (the foot of Pecan street) by the Austin chalk (Niobrara), showing a clear unconformity between them.

The abrupt manner in which the Shoal creek limestone succeeds the *Exogyra arietina* clays at Austin and the marked faunal difference between them is indicative of a sudden physical change in sedimentation, and, were it not that there is a more marked unconformity between the Shoal creek and the overlying Benton beds, I would be inclined to place the former in the Upper Cretaceous series rather than in the Lower, although, paleontologically, it differs from both.

* Fourth Annual Report Geological Survey of Texas, 1893, pp. 277, et seq,

† Third Annual Report Geological Survey of Texas, 1892, pp. 348, 349.

‡ American Geologist, December, 1892.

The molluscan species found in the Shoal creek limestone are sparsely distributed and not abundant. During two years' residence in Austin my wife and myself collected the following species, all but three of which are new: *

| | |
|---|---|
| *Rotalia* sp. | *Homomya*, sp. nov. |
| *Textularia* sp. | *Panopæa*, sp. nov. |
| Three genera of corals, unstudied. | *Turritella*, sp. nov. |
| *Hemiaster calvani*, Clark. | *Globiconcha*, sp. nov. |
| *Alectryonia*, probably *diluviana* of Lamarck. | *Fusus*, sp. nov. |
| *Exogyra*, sp. nov. | *Anchura* (?), sp. nov. |
| *Vola roemeri*, Hill. | *Pterocera shumardi*, Hill. |
| *Pinna*, sp. nov. | *Cerithium* (?), sp. nov. |
| *Spondylus*, sp. nov. | *Trochus*, sp. nov. |
| *Cardium*, sp. nov. | *Nautilus*, sp. nov. |
| *Venus*, sp. nov. | *Hoplites*, sp. nov. |

These species collectively represent an entirely new fauna in the American Cretaceous. Its corals have not been found either in the beds above or below; its echinodermata, especially the genus *Hemiaster*, are found only in the upper series and not in the underlying Comanche. It contains one alectryonate oyster provisionally referred to *O. diluvina*, which is found in the Comanche beneath, and one form which is clearly an antecedent form of the *Exogyra costata* group of Upper Cretaceous beds. It contains none of the Grypheate oysters or other mollusca which characterize the Comanche. It has no Inocerami which specially mark the Upper Cretaceous, and none of the Rudistæ of the Lower. In fact, it is a unique fauna, and represents south of the Brazos either deep-water beds corresponding to the shallow Dakota north of that river or the time represented by a land hiatus which immediately preceded the latter epoch. As it also lies above beds which can with safety be called Gault and below beds (Benton and Niobrara) which are Turonian, this would probably place it near Cenomanian time.

*Exogyra arietina Beds.*—These beds† form a deposit of laminated greenish blue clay some eighty feet in thickness at Austin, where it has its typical occurrence. This clay outcrops immediately beneath the Shoal creek limestone coincident with its extent and rests upon the uppermost band of the underlying limestone group—a paleontologic horizon which I shall designate as the *Kingena* (*Terebratula*) *wacoensis* ‡ bed.

* The descriptions of this fauna will be published as nearly simultaneously with this paper as possible. The type specimens are in the Museum of Johns Hopkins University, and are being studied by Professor W. B. Clark.

† Originally defined by Shumard. Trans. Acad. Sci., St. Louis, vol. 1, pp. 584, 586.

‡ There are but two brachiopod forms in the Comanche, both of which have been examined by Mr Charles Schuchert, who reports that they belong to the genus *Kingena*, hitherto not reported in America. Each of these occurs in two well defined stratigraphic horizons—the one here defined, and the other in the Duck creek beds of Denison.

About midway on the vertical extent of the clays, fossils of the peculiar *Exogyra arietina* of Roemer occur in the greatest abundance, weathering out individually and in perfect preservation. To these shells, especially the umbonal region, are attached small cubes of pyrite, which quickly decompose, coating the shells with a thin layer of brown hematite and probably converting the lime into numerous intercalated seams of fibrous selenite, which abounds in the vicinity of the shell horizon. Sometimes the shells are cemented into thin indurations of argillaceous limestone, which at places makes a persistent band in the middle of the clay bed.

Above the zone of *Exogyra arietina* the clays are again somewhat barren until near their summit, where they become slightly arenaceous and contain impure limestone slabs bearing other fossils, most of which also occur in the upper layers of the limestone beds underlying the *E. arietina* clays. The *E. arietina* beds terminate upward with a horizon of Grypheate oysters, which has been called "*Gryphæa pitcheri*," Roemer, "*G. navia*," and "*G. pitcheri*, var. *navia*," in the writings of Roemer, Shumard, White, the writer, and in all the reports of the Texas Survey. This Gryphæa is none of them, however, but an entirely distinct species—the *Gryphæa mucronata* of Gabb*—and I shall hereafter so designate it. *Gryphæa mucronata* is an especially characteristic fossil of the *Exogyra arietina* beds, and I have found it in no other horizon. The lower surface of the overlying Shoal creek limestone, which was deposited upon the *G. mucronata* beds, is sometimes undercoated with this species (as has been noted by Taff),† but it clearly belongs with the clay beds.

The fauna and flora found in the *Exogyra arietina* beds at Austin is as follows:

An undescribed endogenous plant resembling *Equisetum* (*b*).‡
*Kingena wacoensis*, Roemer (*b*) (*d*) (*f*).
*Diplopodia texanum*, Roemer (*e*).
*Exogyra arietina*, Roemer (*a*).
*Gryphæa mucronata* Gabb (*G. pitcheri*, var. *navia* of various writers) (*c*).
*Neithea texana*, Roemer (*b*).
*Lima* sp. (*b*).
*Plicatula* sp. (*b*).
*Stearnsis robbinsi*, White (*b*) (*d*).
*Protocardia texana*, Conrad (*b*).
*Pachyma austinensis*, Shumard (*b*).
*Dentalium* sp.
*Turritella* sp. (*b*).

Paleontologically the *Exogyra arietina* beds at Austin are limited at the top by the zones of *Gryphæa mucronata*, Gabb, and below by the

* See Geological Survey of California: Paleontology, vol. 1, p. 274.
† Third An. Rept. of Texas Geol. Survey, pp. 347, 348.
‡ Species marked (*a*) are in medial band.
" " (*b*) are from indurated layers of upper part.
" " (*c*) are from the top beds of the clays.
" " (*d*) only a single species found in these beds.
" " (*e*) determined by W. B. Clark.
" " (*f*) determined by Charles Schuchert.

culminating horizon of *Kingena* (*Terebratula*) *wacoensis*, Roemer. *Exogyra arietina*, Roemer, and *Gryphæa mucronata*, Gabb, are found in these beds only, in the mid-Texas sections, and mark a distinct fossil zone in the Texas Cretaceous; the other forms mentioned occur in underlying faunas. This fauna is the upward limit of the grand fauna of the Washita division, the sub-faunas of which show connection by a few common binding species. On the other hand, not a single species passes upward from the *Exogyra arietina* beds into the Shoal creek (Vola) limestone, thus showing between these beds a life-break as marked as is the lithologic change.

To the southward of the Colorado these clays appear at various places along the great Balcones fault at least as far as Del Rio, 200 miles southwest of Austin, where they cross the Rio Grande in a bed of greatly increased thickness.

Northward from Austin the *Exogyra arietina* clays continue as far as the Brazos and maintain the same relative position between the limestones below and above. The medial limestone bands before mentioned become thicker and more pronounced to the northward. North of the Brazos the impure limestone bands increase in proportion to the clays until, at Denison, the latter have entirely disappeared, probably by erosion,* and the Main street limestone alone represents there the *Exogyra arietina* clays and Kingena bed at Austin, and their respective faunas are almost identical.

While the Kingena zone at Austin lithologically belongs with the underlying limestones (Shumard's Washita limestone beds, in part the Fort Worth limestone of my former nomenclature) paleontologically its affinities are with the *Exogyra arietina* beds, as it continues to be the base of this terrane to Red river, where it is part of the Main street limestone, and is separated from the Fort Worth limestones by the intercalation of a great thickness of beds and faunas which apparently has little or no representation in the Austin section. This is discussed more fully under the head of the Denison section.

Fort Worth Limestones.—The *Exogyra arietina* beds rest abruptly upon a group of impure white limestones, of regular banding, and alternate with marly clays—the Forth Worth limestones of my previous nomenclature. This name I now propose to restrict to the thicker, lower beds, as shown in figure 3. This is the most conspicuous lithologic phase of the Washita division. The following section and details of these beds are noted:

The strata of the lower portion of the section is composed of thicker alternations than the upper, although they all have the same white color.

*One mile east of Handley, in the Fort Worth section, the clays have a great thickness above the Main street limestone. Both are here overlapped by Dakota.

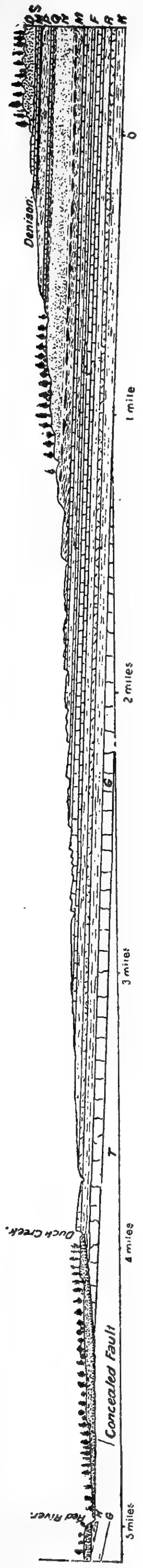



FIGURE 3.—*Profile and Section of Washita Division from Denison to Red River.*

*D* = Dakota; *M S* = Main Street; *P* = Paw Paw; *Q* = Quarry bed; *N* = North Denison; *M* = Marietta; *F* = Fort Worth; *R* = Duck Creek; *K* = Kiamitia; *G* = Goodland; *T* = Trinity.

The fossils occur throughout in definite zones and associations. The thicker Fort Worth beds at the base may be paleontologically characterized as the zone of the unique *Epiaster elegans* of Shumard (*Macraster texanus* of Roemer)* and the *Ammonites* (*Schloenbachia*) *leonensis*, Conrad.

Above these is a bed of clay, almost an agglomerate, of *Gryphæa pitcheri* of Morton, not others.† Associated with this is the unique oyster *Alectryonia carinata*, a familiar European form, occurring only at this horizon in the American section.

At the top of the column is the massive Kingena limestone, which is set with Kingenas like raisins in a pudding. Paleontologically, the term Fort Worth limestone should be hereafter limited to the lowest member of this Austin section or to the thicker beds carrying *Epiaster elegans* and *Schloenbachia leonensis*, for the few feet of upper marls are probably the southern attenuation of the lowest Denison or Marietta beds. The lower (Preston) subdivision of the Washita has not been found at Austin. Let us now compare the Austin section with that of Denison.

*Denison Section.*—At Red river the Washita division is much more fully developed, presenting several distinct subdivisions which do not occur at Austin, the whole section thereby being greatly thickened.

Kiamitia Clays.‡—The firm, chalky, crystalline Goodland limestones, the northern representative of the Fredericksburg division, are succeeded by about fifty feet of dark colored, marly, laminated clays, which are often nearly black before oxidation. They alternate with thin flags of dark blue limestone, oxidizing dirty yellow, and are composed almost entirely of the shells of *Gryphæa forniculata* of

* Neues Jahrbuch für Geologie, Jahrgang, 1888.

† *G. washita*, of my making. This is the only form of the five distinct species of *Gryphœa* which have been almost inextricably confused under the name of *G. pitcheri*, which is Morton's original species. The whole subject is being treated by the writer in a separate paper.

‡ First defined in Bull. Geol. Soc. Am., vol. 2, p. 515.

White.* These beds have many areas of outcrop in northern Grayson county, especially near old Preston and in southern Indian Territory.†

In their stratification and alternations of clay and stone they resemble the Walnut clays underlying the upper lime beds of the Comanche peak or Fredericksburg division, thus indicating similar conditions of deposition. In the upper part of the clay the layers become more calcareous (marly) as they pass by insensible transition into the Duck Creek beds.

The Kiamitia beds ‡ mark a well defined shallowing and beginning of the oscillatory upward movement which characterizes the Washita division. Paleontologically these beds, with the overlying Duck Creek chalks, constitute a single fauna, as they have many species in common. The following forms, however, have been noted in the Kiamitia:

*Epiaster whitei*, Clark.
*Holaster comanchesi*, Marcou.
*Gryphæa forniculata*, White (*G. pitcheri* and *G. roemeri* of Marcou).
*Avicula leveretti*, Cragin.
*Cyprimera* (?) sp. (not *C. crassa*, Meek).
*Protocardia* sp.
*Ammonites peruvianus*, von Buch.
*A. vespertinus*, Morton.

Duck Creek Chalk.§—The Kiamitia alternations increase in marliness, and their limestones become chalkier without break until they culminate in a bed of massive, chalky limestone about 50 feet thick, which in turn grades upward into marly clay.

The importance of these beds in the Cretaceous system has been entirely overlooked, but they are of unusual historic interest, for they contain a unique fauna, which has been partially described and illustrated by Professor Jules Marcou.|| This writer was the first to correctly refer any of the beds of the Texas Cretaceous to the Lower Cretaceous. Although the great series of rocks to which they belonged was not at that time appreciated, Professor Marcou clearly distinguished the Lower Cre-Cretaceous age of the fossils, referring what are now known to be the *Caprotina texana* beds to the Neocomian and what are now defined as the Preston beds to the Gault (greensand and marly chalk), and deserves credit for having alone of all the earlier writers on the subject perceived and announced the existence of the Lower Cretaceous rocks of the Indian Territory-Texas region, and I wish to express clearly, as I have

* This is the form called *G. pitcheri*, var. *forniculata*, in my previous writings. It is the *Gryphæa pitcheri* of Marcou, Geol. North America, p. 38, pl. iv, figs. 5, 6, and also called *Gryphæa pitcheri* throughout the Texas reports.

† The buildings of old fort Washita, Indian Territory, are constructed of this stone.

‡ Mr Taff places these beds in the Fredericksburg or Comanche peak division. This is merely a question of opinion.

§ In their writings Taff and Cragin include these beds and their fossils in the Fort Worth limestones.

|| Geology of North America, Zurich, 1858, pp. 26, 27.

done before, my recognition of this work.* The study of these beds at Preston and Fort Washita, and the discovery of their correct position in the series, has given the writer an appreciation of Professor Marcou's fossils that was not previously possible.

Upon the question of whether the Kiamitia clays and Duck creek chalk are or are not of the age of the Gault, I am not prepared to commit myself, further than to say that they present such striking paleontologic resemblances to it that they cannot be placed elsewhere, and that they are certainly not Senonian, as first alleged by Dr G. G. Shumard † and maintained by others. They succeed without break the Caprina limestones, which are upper Neocomian beyond all reasonable doubt.

The Kiamitia and Duck creek beds collectively can appropriately be called Preston beds in honor of Professor Marcou's type locality, where the beds are best exposed. Together they contain the following fauna :

*Kingena choctawensis*, Shumard.
*Epiaster whitei*, Clark.
*Holaster comanchesi*, Marcou.
*Gryphæa forniculata*, White.
" *pitcheri*, Morton.
*Exogyra plexa*, Cragin.
*Inoceramus*, sp. nov.
*Avicula leveretti*, Cragin.
*Pholadomya*, sp. nov.
*Hamites* (?) *fremonti*, Marcou.
*Ammonites brazoensis*, Shumard.
" *belknapi*, Marcou.
" *gibbonianus*, Lea.
" *acute-carinatus*, Shumard.
" *vespertinus* (?), Morton (not *A. texanus*, Roemer, as has been alleged).

This is one of the best defined and most specialized faunas of the whole Comanche series. The *Kingena choctawensis* differs in shape from *K. wacoensis*, but may prove a variety of the latter species. The zone of its occurrence is certainly far below that of the typical *K. wacoensis*. The genus *Inoceramus* here in the Duck creek beds makes its only authenticated appearance in the Comanche series. The undescribed species resembles figures of *I. neocomensis* and *I. labiatus* of Europe, and is entirely different in form from the Inocerami of the Upper Cretaceous.

The Ammonitidæ are especially well differentiated and are worthy of careful study. Only three of all the Duck creek species occur in other beds so far as observed.

Fort Worth Limestones.—These limestones succeed the highly marly clays of the Duck creek chalk without perceptible break, and the sedimentation between them is continuous.

In the Denison section they have, as at Austin, the same alternations of dimension layers and marls so characteristic of the beds there and throughout their extent. The buff-white limestones (blue interiorly) quickly disintegrate on weathering. These hard layers decrease in thick-

* Bull. U. S. Geol. Survey, no. 45, p. 74 et seq.
† Exploration of the Red River of Louisiana, etc., 1852, p. 158

ness and in proportion to the marls in ascending series, the latter passing without break into the ferruginous Denison beds.

While these beds resemble the Duck creek limestones in color and composition, the material of the latter is certainly clearly distinguishable by its purer, finer grained and more chalky character. If there is any doubt upon this point, however, its paleontologic differentiation is unmistakable.

Paleontologically the Fort Worth limestones may be defined in the Denison section as including the beds between the hemeras of the undescribed *Inoceramus*, sp. nov., above mentioned and *Ostrea quadruplicata*, Shumard.

The paleontologic character of the Fort Worth beds is very persistent throughout their extent, but their lithologic aspect is sometimes repeated in some of the horizons of the Denison beds in their southward extension, as they become more marly away from the Ouachita shore at Denison. In the Denison section the beds are about 200 feet thick, and the following fossils, the list of which is subject to future revision, have been reported from them:

*Fauna of the Fort Worth Limestone.**

*Eschara* sp.
*Epiaster elegans*, Shumard.
*Holectypus planatus*, Roemer.
*Leiocidaris hemigranosus*, Shumard.
*Cidaris texanas*, Clark.
*Pyrina parryi*, Conrad.
*Ostrea carinata*, Lamarck.
" *diluviana*, Lamarck.
*Gryphæa pitcheri*, Morton.
" *sinuata*, va. *americana*, Marcou.
*Plicatula placunea* (?), D'Orbigny.
*Spondylus hilli*, Cragin.
*Vola bellula*, Cragin.
*Neithea catherina*, Cragin.
" *occidentalis*, Conrad.
*Janira wrightii*, Shumard.
*Lima generosa*, Cragin.
" *wacoensis*, Roemer.
*Turritella seriatim granulata*, Roemer.
" *planilateras*, Conrad.
*Pleurotomaria austinensis*, Shumard.
*Nautilus texanus*, Shumard.
*Ammonites leonensis*, Conrad.

Denison Beds.—Succeeding the Fort Worth limestone in the North Texas section is a group of lithologic and paleontologic members, for which I proposed the collective name of the Denison beds in previous papers,† and deferred a minute definition of its members until a future occasion.

*The term Fort Worth limestone is applied to several distinct beds by Mr Taff, who appears to have used the term sometimes to describe lithologic appearance as well as position. See section, pp. 269, 270, of his report in Fourth Annual of the Texas Survey, where he has it twice, with "Denison marls" between. He also includes in it (p. 26) the Denison fauna.

†See Preliminary Annotated Check-list of the Invertebrate Cretaceous Fossils, Austin, 1884, p. xxiv; Bull. Geol. Soc. of Am., vol. 2, May, 1891, p. 517; On the Occurrence of Artesian and other Underground Waters in Texas, etc, Washington, 1892, p. 88.

The Fort Worth limestones, characterized by whitish and very slightly yellow tints, begin to show at their top strong ferruginous colors. This ferrugination is quite sudden, and the limestones become less frequent and alternating, and clays and sands begin to predominate. This apparently trivial feature is really an important one, for it indicates change in the condition of sedimentation, and, as I shall show, it is accompanied by certain faunal changes, throwing light on the Austin section. This change is perceptible in the beds as far southward as fort Worth.

The Denison beds at Denison consist of the following members:* Main street limestone; Paw Paw shales; North Denison sands; and Marietta marls.

The Marietta beds, the lowest member of the Denison beds, consist oı friable, brown laminated clays. Throughout their extent in the Red river region they are marked, a few feet above their base, by peculiar segregations, pseudo-concretions, in the shape of large, thin lenses of indurated silicious limestone, which are often four or five feet in diameter and from one to two feet in thickness, and which split into fissile laminæ upon weathering. These beds are marked by the association of several interesting species, the most characteristic of which is that of *Alectryonia carinata*, associated with *Gryphæa pitcheri*, Morton, and the beautiful echinoid *Leiocidaris hemigranosus* of Shumard, which occurs near the base. This is the horizon which, in my first section of the Texas Cretaceous, I described as that of *Gryphæa pitcheri*, associated with *Ostrea carinata*.† These fossils occur in thin brecciate slabs, good specimens of which are in the collections made by me for the United States Geological Survey and the Texas State Survey. It was also from these beds on Little Fossil creek, six miles north of fort Worth, Texas, that I collected the types of the rare species *Stearnsia robbinsii*, White, *Dalliaconcha invaginata*, White, and *Ophioglyphia texana*, Clark,‡ the horizon and geologic position of which has not hitherto been published, I believe.

The ferruginous character of these beds extend southward as far as

*Mr J. A. Taff misinterpreted my definition of the Denison beds in the plural, and inferred that I meant by them only the basement bed of the group of beds. He uses the term in the singular for its lowest member. Proceeding upon this erroneous impression, probably justified by my imperfect definitions, he presented an erroneous criticism of my work in the American Geologist of December, 1892. Since that writing he has visited and published on the Denison section, and no better proof of the correctness of my conclusions can be given than an examination of the details of his sections in the Fourth Annual Report of the Texas Geological Survey. In this report he speaks of the lower (Marietta) bed without definition as the "Denison beds," the "Denison marl," the "Denison bed," etcetera. The term "Denison beds," as used for the group, has precedence and should not be confused with Mr Taff's application of the term. (See Third and Fourth Ann. Repts. Texas Geol. Survey, and Am. Geologist for November and December, 1892.)

†Am. Jour. Sci., April, 1887.

‡Proc. Phila. Acad. Sci.

Fort Worth and Cleburne, but at some point not yet determined between the latter place and the Brazos its color becomes lost. The paleontologic horizons, however, continue southward under the lithologic aspect of the Fort Worth limestone, constituting at Austin the few feet of marly clays with *G. pitcheri* between the zones of *Ammonites leonensis* and *Kingena wacoensis*, which form the upper beds of the Fort Worth limestone there.

*Fossils of the Marietta Beds.*

| | |
|---|---|
| *Leiocidaris hemigranous*, Shumard. | *Gryphæa pitcheri*, Morton. |
| **Ophioglypha texana*, Clark. | *Ostrea carinata*, Lamarck. |
| **Gervillospis invaginata*, White. | *Trigonia emoryi*, Conrad. |
| **Ostrea quadriplicata*, Shumard. | *Plicatula dentonensis*, Cragin. |
| †*Stearnsia robbinsii*, White. | |

Without break the brown Marietta clays grade upward into the North Denison sands—beds characterized by alternations of excessively ferruginous, laminated sands and clay, which by infiltration and induration are sometimes converted into a fossiliferous hematite. The hematite strata are often of great hardness and are excessively fossiliferous. The sands of these beds could easily be and have been confused with the Dakota sands of the South Denison, but their distinct stratigraphic position is beyond question.

The fossils are abundant and beautifully preserved, both as shells and moulds. The species are mostly littoral mollusks not occurring in the lower beds, such as *Axinea*, *Nuculæa*, *Corbula*, *Tapes*, *Turritella*, etcetera, which coincide with their physical composition in the testimony that these beds are more littoral than others of the Washita division, and are indeed its shallowest, most littoral deposits.

The typical occurrence of these beds is in the northern half of the city of Denison. They reappear along an east-and-west strike in Indian Territory, from east of Marietta eastward to the Missouri, Kansas and Texas railroad.

It is interesting to note that the outcrop of these sands is occupied by the same kind of forests as the Dakota sands of South Denison in their narrow extent along the western border of the lower Cross Timbers, so that the areal extent of the lower Cross Timbers can no longer be said to be exactly coincident with the Dakota, but it includes in its western portion a very narrow strip of the Lower Cretaceous.

The sandy ferruginous beds are not sharply differentiated from the overlying and underlying beds, either paleontologically or stratigraph-

* Has not been seen by the writer south of Tarrant county.
† Occurs in *Exogyra arietina* beds at Austin. Rare.

ically. They represent a zone of excessive ferrugination in the section. At Denison* they are from 100 to 130 feet thick. Their summit, for convenience, may be placed at a zone locally known as the "quarry limestone" band, where the unique *Ostrea quadruplicata* has its greatest development. Its fauna passes into that of the overlying Paw Paw clays. The sands rapidly thin out to the southward, not occurring in the Trinity section.

The North Denison sands are inseparable from the overlying Paw Paw clays. These clays are of a light drab color, very thinly laminated and contain many beautiful fossils, a species of Turritella predominating, the nacreous substance of which is preserved unaltered, like some of the fossils of the Claiborne Tertiary, and which fall to pieces upon exposure to the air. The clays are exposed in the banks of Paw Paw creek, in the southern and eastern portion of the city of Denison; at the mineral spring on the head of Duck creek, in northwest Denison, and elsewhere.

The species of the North Denison sands and Paw Paw clays have not been completely described, but the following are recognizable as constituting their fauna:

*Fauna of the Paw Paw Clays and North Denison Sands (Denison Beds in part).*

*Ostrea quadriplicata*, Shumard.
*Corbula* sp.
*Axinæa* sp.
*Volsella* sp.
*Tapes* sp.
*Cytherea* sp.
*Tellina* sp.
*Protocardia texana*, Conrad.
*Pholadomya* (?) *postextenta*, Cragin.
*Cyprimera* sp.
*Anchura mudgeana*, White.
*Turritella* sp.
*Ammonites emarginatus*, Cragin.

The Denison beds terminate in the beds of the Main street limestone, not over thirty feet in thickness, which underlies the main street of the city; strikes in an east-and-west direction, and also outcrops on the bluffs of Paw Paw creek, south and east of the city. This limestone is coarse grained, of irregular hardness and composed of minute shell fragments; is of a dull yellow color upon weathering, but is white upon fracture, and burns into a very impure lime with hydraulic properties. It is separated by thin beds of clay.

The Main street limestone is everywhere surmounted unconformably by the coarse ferruginous sands and silicious iron ores of the Dakota. This is the only positively known break in the sedimentation from the beginning of the lowest (Trinity) Cretaceous beds. The Main street

*The "Denison marl" of Taff: Fourth Ann. Rept. Geol. Survey of Texas, p. 273.

limestone contains a characteristic fauna which has important bearing upon our subsequent discussion. This fauna is as follows:

*Fauna of the Main Street Limestone.*

| | |
|---|---|
| *Kingena wacoensis*, Roemer. | *Exogyra sinuata*, Marcou. |
| *Orthopsis*, sp. nov. | " *drakei*, Cragin. |
| *Holaster* sp. | *Janira texanus*, Roemer. |
| *Holectypus planatus*, Roemer. | *Protocardia texanum*, Conrad. |
| *Holaster simplex*, Shumard. | *Hoplites texanus*, Cragin. |
| *Ostrea quadriplicata*, Shumard. | *Turrillites brazoensis*, Roemer. |
| *Gryphæa mucronata*, Gabb. | *Pachyma austinensis*, Shumard. |
| *Exogyra arietina*, Roemer. | *Protocardia texanum*, Conrad. |

It will be noted that this fauna is different from the species or associations of the underlying Denison beds. It is that of the *Exogyra arietina* clays and Kingena limestone of our Austin section. The whole thickness of the underlying Denison beds is an intercalation barely represented in the Colorado section. It is also noticeable that it presents a similar association (not species) of Echinoids and Grypheate and Exogyrate ostreidæ which characterize the beds of the Washita division below the Marietta bed. In other words, it marks a return of clearer water environment and with a time-modified fauna of the lower Washita which disappeared from this shore upon the slight elevation and shallower impure sedimentation of the Denison beds.

*General Remarks on the Sections.*—The Denison beds below the Main street limestone with their littoral faunas thin out with great rapidity southward or off-shore from Red river, the 328 feet at Denison only being represented, if at all, by the ten feet of marly calcareous clays below the Kingena zone at Austin, and even in this the littoral species have mostly disappeared. These facts afford us a standard of appreciation of the conditions under which the marly calcareous clays which are so common in the Comanche series were deposited. They represent the off-shore (archibenthal) or finest physical and chemical sediments and are not littoral. They should be represented near the Cordilleran front, as at the Ouachita shore, by thicker arenaceous, littoral, plant-bearing terranes.

It will also be seen that the nearer-shore Denison section is composed of a great many more lithologic members than the Austin, being seven in number instead of three at the latter place. These seven beds at Denison are really represented by only two members at Austin, the *Exogyra arietina* clays and the Fort Worth limestone, while the uppermost member of the Austin section, the Shoal creek limestone, has no representative whatever at Denison. It may have been once deposited there (under what conditions cannot be said); but, if so, it was com-

pletely eroded away during the time represented by the great hiatus between the Main street (*Exogyra arietina*) limestone and the Dakota.

In contrast with the variations of the shallower Denison beds the Fort Worth limestone is more persistent and the least variable lithologically of all the members of the Washita. It shows the same general characteristics from Bexar county, west of San Antonio, 400 miles northward to near Fort Washita, Indian Territory. The members above and below it show a progressive variation throughout their extent.

The probable absence of the Preston beds (Kiamitia and Duck creek) in the Austin section I am as yet unable to interpret.

### *WESTERN SHORELINE OF THE WASHITA DIVISION.*

The Washita shoreline is not yet interpreted over an area from the western border of our map westward to the 104th meridian, the sedimentation having been destroyed by the great mid-Tertiary erosion,* but there is evidence that it extended from the latter line southwestward via El Paso. Along this line the beds again appear, but, as would naturally be expected, under slightly modified conditions, their color and chalky aspect having been altered into bluer and harder conditions by the mountain movements, and their sediments having been derived from the ancient nucleal Rocky mountain land. Nevertheless they maintain their individuality in such a manner as to render their identity unquestionable. The series of vertical sections shown on plate 13 illustrate the occurrence of these beds along the north and south line in this region. The most northwestern outcrop of the beds is at Tucumcari, New Mexico, where they occur under the conditions previously described† by the writer.

The writer has studied most of this western region only in a cursory manner, but has examined with special care the sections at Tucumcari mesa, New Mexico, and at El Paso, points along the western shoreline some 300 miles apart. At Tucumcari the stratification is undisturbed, but at El Paso it is greatly broken by faulting and dioritic and porphyritic intrusions, rendering minute measurements and interpretations of the section so difficult that I have had no time as yet to undertake them. At the latter place, however, the Washita division abuts against the old Paleozoic shore of the Organ mountains, and consists of the same general character, with variations in detail, as at Denison, namely, an upper ferruginous littoral member and a lower calcareous deeper member, showing the same shallowing upward. No trace of the Shoal creek limestone fauna has yet been found in these western beds, although the name

* On the Occurrence of Underground Water, pp. 135, 136.

† Science of July 14, 1893.

of this formation has been erroneously used in connection with them in a recent publication.*

Paleontologically these beds of the western shoreline show slight variation from those of the east. The same distinguishing species, such as *Gryphæa mucronata*, Gabb, *O. quadricostata*, Shumard, *Trigonia emoryi*, Conrad, of the Denison beds, and *Schloenbachia leonensis* of the Fort Worth, occur, but some new species, such as *Grgphæa dilatata*, Marcou, and *Turbinolia texana*, Conrad, are initiated, and some of the Comanche Peak species, such as *Chemnitzia occidentale*, Gabb, range up into the Washita. These variations over such great distances are naturally to be expected, and their study will ultimately enable us to correlate all synchronous deposits of Washita time over the Mexican and South American region.

Each of the littoral formations shoring against the Ouachita mountain system should be studied in its extent and variation over the archibenthal region southward and the results set forth in the same way as I have endeavored to present my studies of the Washita division.

### Oscillations of Land and Sea recorded in the Region.

Where sediments present such a uniform and persistent extent as the members of the section of this region, and where they are found in such definite succession, it is possible to make some very accurate interpretations from them of the subsidence and elevation of that portion of the ocean's margin in which they were laid down and of the land from which they were derived. The stretch of Plateau gravel across Arkansas and Texas for 600 miles at the elevation of 500 to 600 feet can mean nothing else than that they once marked a marine level of deposition, and that the land has been elevated to the present height since they were laid down. Furthermore, this elevation was not local or spasmodic, but general or epirogenic. In this region we have records since early Mesozoic time of five of these periods, when the oscillations of the land and sea have brought the region to marine level or elevated it far above. The records, so far as they can be interpreted, are as follows:

The earliest, where our studies begin, is the Trinity shoreline, which marked the great baseleveling of the land and its invasion from the southward in late Mesozoic time by the waters of the Atlantic. They are, at their beginning, littoral near-shore deposits, as shown by their structure and organic remains.

The Glen Rose beds, mostly brecciated and chalky limestones and

*See American Geologist, November, 1893, pp. 309–314. The paleontologic nomenclature, range and formation names used in this article are unreliable.

marls, show that the Trinity subsidence continued until the conditions for deeper clear water deposits had been reached.

The Paluxy sands show a return to the littoral conditions of the Trinity and the beginning of a second subsidence. The Walnut clays that succeed them show slightly deeper and further off-shore sedimentation. The massive chalky Goodland limestones show a still deeper and quieter condition of sedimentation. These three beds (Paluxy, Walnut and Goodland) represent a progressive subsidence during Fredericksburg time, until the ocean was comparatively deep over central Texas and its western shore was far westward toward the Rocky mountain region.

The Kiamitia clays mark the beginning of the progressive shallowing during the Washita time. They show a shallowing condition after the deposition of the Goodland limestones and a return to those prevailing when the Walnut clays were deposited—even shallower, for there is less of the fine lime precipitate and more carbonaceous matter in them.

The Duck Creek chalks again indicate subsidence, like the Goodland limestone, but to a less degree, as they are not so pure a chalk. The alternations of marly clays and limestones in the overlying Fort Worth limestones shows long continued shallowing.

The Marietta beds reveal the progression of this shallowing to a more littoral stage, finally culminating in the North Denison sands, when the material and excessively littoral fauna indicate the nearest approach to land conditions.

The Paw Paw shales show that slight subsidence had again begun, which was slightly deepened during the Main street limestone epoch, after which there was a general return to land conditions which prevailed throughout the region before the second grand subsidence or that of Upper Cretaceous time began.

This mid-Cretaceous epirogenic elevation could not have been of long continuance, but it must have been of great magnitude and of sufficient duration to completely destroy the faunal continuation of the marine life of the Lower Cretaceous. The interpretation of the effects of this movement in the Cordilleran history of our continent is one of the most important geologic problems of the future.

The Dakota, like the Trinity, is a deposit at marine baselevel; estuarine, littoral and lacustral probably in places, but historically recording the shallowest deposits and marking the second grand Cretaceous invasion of the west by the Atlantic shoreline and the commencement of the second or Upper Cretaceous epirogenic subsidence.

The blue clays of the Eagle Ford shales (Benton) represent the progressive deepening, and the Austin (Niobrara) chalk represents the culmination of this subsidence. The overlying Ponderosa marls and beds

of the Glauconitic, as in the case of the Washita division of the Comanche series, represent a wavering but progressive shallowing not yet completely interpreted, and it can only be stated that this time was marked by a series of slight oscillations, and that the present seems to be one of elevation.

All these movements and my estimate of their amplitude are graphically represented in the following figure:

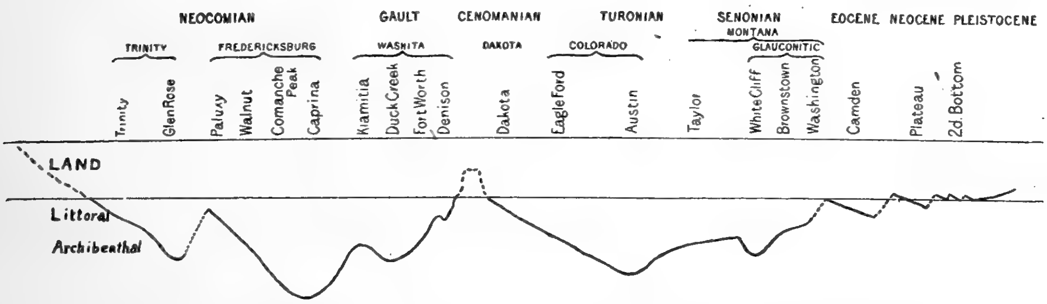



FIGURE 4.—*Oscillations of Land and Sea shown in Sediments of Red Riv r Region.*

It should be remembered that these movements in the Red river region, as proved by the great extent of the deposits southward to the Rio Grande, were epirogenic, and that they should be recorded, perhaps in varied sediments or erosion surfaces, in the history of the Great plains and eastern Rocky mountain region.

In the basement Eocene we have still another period when this region was the shoreline with corresponding littoral deposition, but the details have not been thoroughly investigated.

The Plateau gravel probably represents the great epoch of Neocene baseleveling, described by McGee under the name of the Appomattox and the Lafayette. I believe, from my limited studies, that ultimately the vicissitudes of its physical history will be closely correllated with those of the Llano Estacado. The details of the later Pleistocene history have not been studied.

In general, it should be remembered that owing to the persistence of the old Ouachita shoreline this Red River region was one in which the average conditions of land and water were near sealevel, while the Rocky mountain region was that portion of our continent which was average upland, and the central Texas region that of great alternations, hence the amplitude of oscillation of each movement was many times greater in the Cordilleran region than in the Red river country. To the westward great epirogenic and orographic movements were taking place through thousands of vertical feet of movement to the hundred here.

For instance, we know that the Trinity level of deposition has been elevated to 4,000 feet in New Mexico, the Dakota and Eocene (Laramie) to 10,000, and the Miocene to 5,000 feet, while all are found below 500 feet in Arkansas.

Nearly all these movements, except the Comanche, have been recognized if not correlated in the Rocky mountain region, but the Comanche has not been noticed because it had not been differentiated when our great physical geologists studied that region and when the Dakota was supposed to be the lowest Cretaceous baselevel epoch. When the Cordilleran region is studied in the light of this later knowledge of the Comanche it will reveal a volume of history now unknown.

## Conclusions as to the Cretaceous Section.

Limited space prevents the amplification in this paper of much desirable detail, but the writer hopes that he has presented the salient facts concerning the structure, especially of the Cretaceous formations. A study of these as here presented cannot but emphasize the fact that in the Arkansas-Texas region they have a completeness of stratigraphic and paleontologic succession such as can be found nowhere else in America, from which many important deductions can ultimately be drawn, and which lead to conclusions somewhat different from those currently accepted.

The writer believes that without the aid of this section, deductions concerning correlation have been in general premature and unreliable, and will be until the paleontology of the six* distinct faunas of the Comanche series are studied, compared and published. These faunas are as distinct one from another as they can be, and each contains important data without which it is utterly impossible for any one to properly understand the life relations of the North American Cretaceous. While species-making has continued until nearly every form has received many names, not a single one of these faunas has been fully published, so that its full meaning can be interpreted, and only two of them approximately published.† Several of them are briefly mentioned in this paper for the first time. With the exception of the Echinodermata,‡ not a single class has been studied systematically with reference to stratigraphic occur-

*These faunas are those of 1. The Trinity division; 2. The Comanche peak beds and Caprina limestone; 3. The Preston beds (Kiamitia and Duck creek); 4. The Fort Worth limestone; 5. The Denison beds; 6. The Shoal creek limestone.

†The faunas of the Trinity division and Caprina limestone. See Proc. Biol. Soc., Washington, 1893.

‡The Mesozoic Echinodermata of the United States, by W. B. Clark. Bull. 97, U. S. Geological Survey, Washington, 1893.

rence. The Ammonitidæ, Vertebrata and Mollusca have not yet been critically classified in print with reference to the light they may throw upon the age of these beds, yet without this essential data the fiat has frequently gone forth that no correlation can be made between the North American Cretaceous and that of similar life periods throughout the world. Without facilities for the publication of a monograph upon the fossils of the Texas section, the writer is at a disadvantage in presenting conclusions, but the faunal charts exhibited at the reading of this paper, but which lack of space prevents publishing, showed that there are substantial grounds for the following conclusions:

We have in the North American Cretaceous, as represented in the Texas section, as complete a succession of beds and faunas as is represented in any known geographic division of the world.

The sequence of life in these beds is such as to justify, in discussing the North American Cretaceous, the application of a more definite subdivision of terms, in harmony with world-wide nomenclature—terms to be used as Eocene, Miocene and Pliocene are employed in America in speaking of the much less defined divisions of the Tertiary.

The North American Cretaceous, of the Atlantic sedimentation, presents the following strong analogies to the European: 1. It is divisible into two distinct systems—an Upper and a Lower—separated by an epirogenic land elevation and stratigraphic break. 2. It is divisible into subgroups, based upon life forms and associations, such as the Neocomian, Gault, Cenomanian, Turonian and Senonian, of the equivalency of the term Eocene, as applied to the Tertiary.

Some of these divisions, so far as studied, such as the Neocomian (Trinity and Fredericksburg divisions), Turonian (Benton division) and Senonian (Glauconitic), reveal a close homotaxial similarity of generic forms to those of other portions of the world.

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The following is a list of the papers on the geology of the Texas region published by the author:

Present Condition of Knowledge of the Geology of Texas (1886). Bulletin 45, U. S. Geological Survey, Washington, 1887.

The Topography and Geology of the Cross Timbers and Surrounding Regions of Northern Texas. Am. Jour. Sci., April, 1887.

The Texas Section of the American Cretaceous. Am Jour. Sci., October, 1887.

Events in North American Cretaceous History, illustrated in the Arkansas-Texas Region. Am. Jour. Sci., April, 1889.

A Portion of the geologic Story of the Colorado River of Texas. American Geologist, May, 1889.

Neozoic Geology of Southwestern Arkansas. An. Report of Arkansas Survey for 1888, vol. 11.

Classification and Origin of the chief geographic Features of the Texas Region. American Geologist, January and February, 1890.

A brief Description of the Cretaceous Rocks of Texas, and their economic Value. Annual Report of the Geological Survey of Texas for 1888.

"Report of Mr R. T. Hill." Ibid., pp. lxxxiii–lxxxviii.

Paleontology of the Cretaceous Formations of Texas. Austin, 1890, folio 1.

A preliminary annotated Check List of the Cretaceous Invertebrate Faunas of Texas. Austin, 1889.

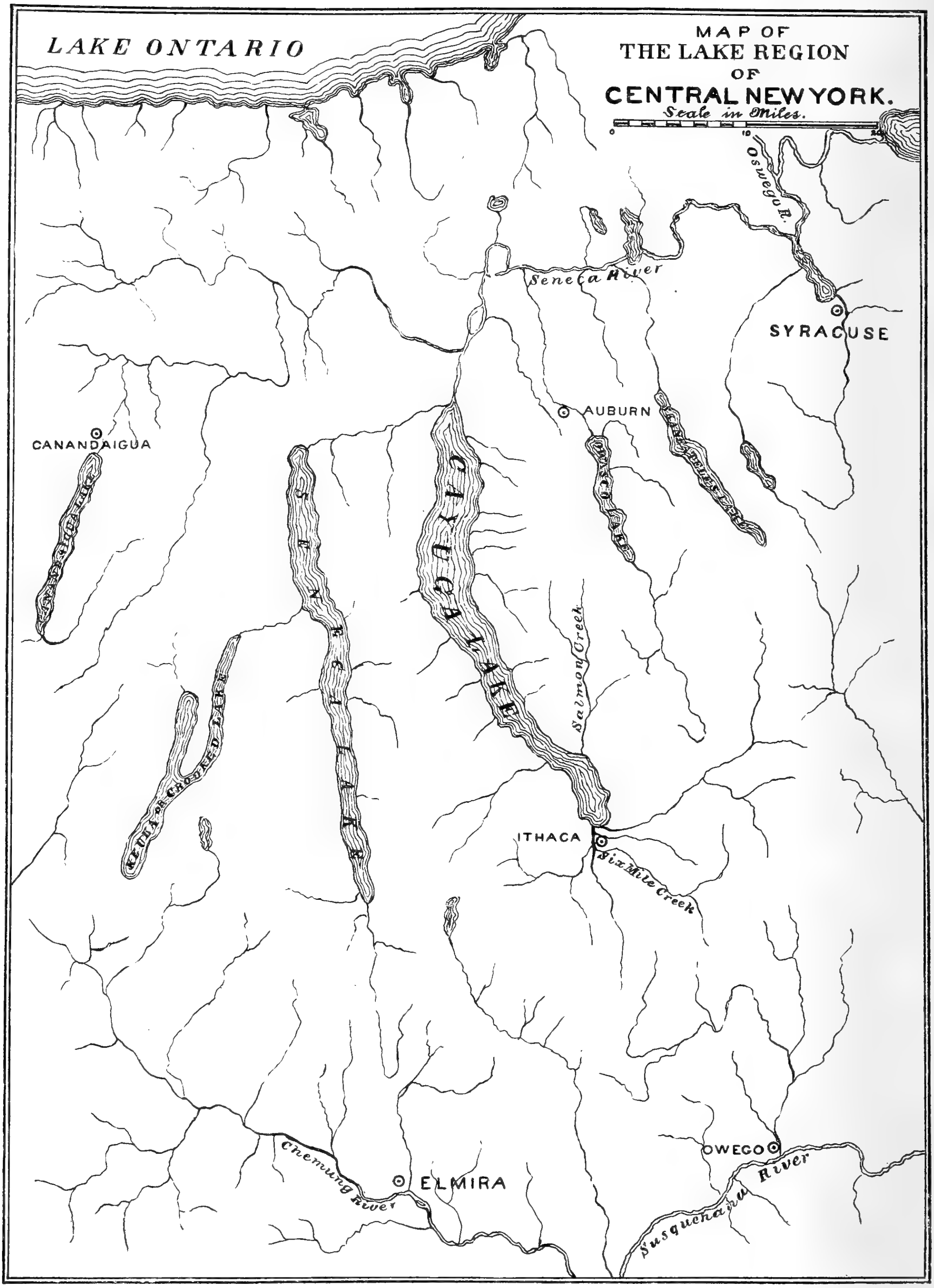
The Comanche Series of the Arkansas-Texas Region. Bull. Geol. Soc. of Am., vol. 2, 1890, pp. 503–528.

Notes on the Texas-New Mexican Region. Bull. Geol. Soc. of Am., vol. 3, 1891, pp. 85–100.

On the Occurrence of artesian and other underground Waters in Texas, etc. 52d Cong., 1st sess., Senate Doc. 41, part 4, pp. 41–166. Second edition entitled Report on Irrigation, 1893. The author is not responsible for the first edition of this paper.

The Invertebrate Paleontology of the Trinity Division. Proc. of the Biological Society of Washington, June, 1893.

The Invertebrate Fossils of the Caprina Limestone Beds. Proc. of the Biological Society of Washington, July, 1893.


MAP OF
THE LAKE REGION
OF
CENTRAL NEW YORK.
Scale in Miles.
LAKE ONTARIO
Oswego R.
Seneca River
SYRACUSE
AUBURN
CANANDAIGUA
CAYUGA LAKE
SENECA LAKE
KEUKA or CROOKED LAKE
Salmon Creek
ITHACA
Six Mile Creek
OWEGO
Susquehanna River
Chemung River
ELMIRA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 5, PP. 339-356, PL. 14 MARCH 22, 1894

# LAKE CAYUGA A ROCK BASIN*

BY RALPH S. TARR

(*Presented before the Society December 29, 1893*)

CONTENTS



## PHYSICAL GEOGRAPHY OF THE REGION STUDIED.

*Finger Lakes.*—In central New York there is a series—a dozen or more in all—of long, nearly parallel lakes to which the general name Finger lakes is applied. Several of these, notably Cayuga and Seneca, are extremely long compared with their width. These lakes, although nearly parallel, are not strictly so, but converge slightly toward a common center at some point near the northern shore of lake Ontario, which lies immediately to the north. At present all these lakes, with the exception of one or two minute ones, drain northward and eventually enter lake Ontario mostly through Oswego river, which flows eastward for a dis-

* The author is indebted to Mr A. S. Eakle for assistance in the preparation of the illustrations accompanying this paper.

tance and then turns abruptly northwestward after having received the waters of Oneida, the easternmost member of the series. Two or three smaller lakes on the western margin of the district empty into Ontario through the Genesee river.

As is pointed out by Dr Lincoln,* Professor Brigham † and others, these lakes are situated in valleys cut in the northern slope of the New York portion of the Appalachian plateau, which is composed mainly of Devonian rocks. Near the head of the lakes there is an irregular divide, high and diverse in topography, which separates the waters of the Chemung and Susquehanna from the north-flowing tributaries to the Saint Lawrence system. This plateau frequently attains an elevation of over 2,000 feet, while the valley bottoms are, in two cases at least, below sea-level. Dr Lincoln ‡ brings out the interesting fact that the plateau is here axially depressed, that is, while the upland is everywhere a plateau, the upland itself, and the valleys in it, are lower in elevation near the center of the district than on the margins. This is brought out by him in a diagram which shows a general sagging of the surface in the center of the district, and in this central portion the two large lakes, Seneca and Cayuga, are in notable depressions, much more pronounced than those on either side.

*Topography of the central Area.*—The topography of the central area is very typical of the New York-Pennsylvania plateau. The valleys of Cayuga and Seneca are broad, gently sloping, smooth sided, linear valleys, in all respects typical of mature rivers. One might well conclude from the form alone that they are nothing more than mature preglacial river valleys. They wind in and out, their southern headwater portions are markedly more diverse than their northern continuations, and as the northern end is approached the hills become lower and lower, until finally they are replaced by a comparatively low plain. Moreover, there are tributaries of mature form, well pronounced both in the southern portion and on the plateau at one side.

*Drainage.*—In most cases the creeks flowing into these lake valleys enter through gorges as a series of rapids and waterfalls—in one case, Taughannock, with a single fall of 190 feet. They drop down, as it were, over the valley slope into the lake. Ordinarily a few miles from their mouths these streams flow in well developed, mature, preglacial valleys, so that on the main valley side and at their mouths alone the gorges and falls exist.§ In one or two cases, however, the stream enters the lake

* Am. Jour. Sci., vol. xliv, 1892, p. 290.

† Bull. Am. Geograph. Soc., vol. xxv, no. 2, 1893, p. 3.

‡ Am. Jour. Sci., vol. xliv, 1892, pp. 290–293.

§ This is a reversal of the usual condition and is just the opposite from the river system as described in text-books, in which the upper course is torrential.

through its preglacial valley. Where this is not the case the old valley in some cases appears to be filled with drift and the present stream near the lake to be cutting a rock gorge in one of the banks of the preglacial valley. This is certainly true of Taughannock, for the old valley is plainly indicated as a gentle sag in the hillside just north of the falls. There is, moreover, in these tributary valleys an appearance of having been rubbed back, as if the valley had been widened by glacial erosion.

The explanation of these phenomena appears to be complex. They are apparently due in part to the widening of the lake valley, in part to the clogging of the tributary valleys with drift near their mouths where the enclosing walls were lower, and in part to the proximity of the terminal moraine, which, in the more southern valleys, actually furnished the drift.

*Cayuga Lake and Valley.*—In the valley of lake Cayuga, commencing at the divide near Summit marsh, where the elevation is about 625 feet above the lake-level, or a little over 1,000 feet above sealevel, the topography is comparatively rugged, the hills rise steeply on either side, and from them streams flow in deep, narrow valleys, evidently preglacial in age. The entire topography indicates that there has been very little glacial erosion at this point, and also very little drift filling, excepting in the main valley. The exact depth of the drift at the divide cannot be told, but it does not appear to be great. It has the appearance of a true divide of destructional origin, and not one of constructional origin, consisting of glacial débris, as has been suggested by some. Indeed, from the steepness of the walls and the depth of the valley, it seems as if the preglacial divide must have been higher than now, having been lowered by glacial erosion.

North of Cayuga lake valley is a considerable accumulation of morainic material referred by Chamberlin* to the terminal moraine of the second glacial epoch. This occupies the valley from the divide nearly to Ithaca, a distance of about ten miles; but it is at this point confined to the valley. Although narrow, rarely having a width of more than a mile, it is extremely well developed and typical and appears to be deep.

This moraine gradually disappears beneath the growing delta-flat upon which the city of Ithaca is built and whose margin is continuous with the sub-lacustrine delta. The delta has a width of nearly a mile and a length of more than two miles. The hillsides come steeply down to this plain and disappear beneath it. They do not gradually merge into this plain, which is a true lacustrine delta, modified only slightly by extremely flat alluvial fans associated with the torrential creeks which enter the valley from the hillsides.

* Third Ann. Report, U. S. Geol. Survey, 1883, pp. 353–360.

From the margin of the delta, lake Cayuga extends northward, with a slightly fluxuous course, for a distance of nearly forty miles, and with a width varying from one mile near Ithaca and Ludlowville to more than three miles opposite Aurora. The enclosing hills, which near the southern end are high though gently sloping, gradually decrease in elevation and angle of slope toward the north, and near the northern end have practically disappeared. At this end the outlet is through an extensive swamp. On both shores of the lake there are high cliffs, but they are particularly well developed on the eastern shore, indicating that waves had a share in their formation.

The surface of the lake is 378 feet* above sealevel, but at the deepest point, near the middle of the lake, there is a depth of 435 feet. For a distance considerably more than half its length the bottom of the lake is below sealevel, and at the deepest point the bottom is 57 feet below tide-mark. The lake is distinctly deeper at its southern end, or at least in its southern half. For nine miles from the northern end the depth does not exceed 100 feet at any point, while at the southern end a depth of 200 feet is found at a distance of one and one-half miles from the delta, and at a distance of three miles the depth is 300 feet.

*Seneca Lake and Valley.*—The valley of Seneca lake exhibits very nearly the same features, but the lake is about five miles shorter, the surface is 440 feet above sealevel and the greatest depth is 618 feet, or 178 feet below sealevel. Almost everywhere the lake is over 300 feet deep, and more than half the lake bottom, the southern half, is over 500 feet below the surface, or distinctly below sealevel.

Professor Brigham† points out that these two lakes are situated with their northern ends in the comparatively hard Helderberg rocks, the lakes themselves being in the soft Marcellus and Hamilton shales, while in the region of the divide to the south the strata are harder and more sandy. This, taken in connection with the gentle southerly dip of the strata and the greater depth of the lakes in their southern ends, has an important bearing upon the question of the origin of the lakes.

## Review of Opinions of previous Writers.‡

It is not surprising that a region so peculiar as the Finger lake district should have attracted widespread attention, but it seems extremely strange that until within a year or two no one should have seen the very

* The facts concerning the lake bottom are obtained from the very excellent maps prepared by the Civil Engineering Department of Cornell University.

† Bull. Am. Geograph. Soc., vol. xxv, no. 2, 1893, p. 17.

‡ This does not pretend to be an exhaustive statement, but discusses all the papers which the author has been able to find.

plain evidence of the origin of these valleys. In the following discussion of the literature it will be found that opinions of different kinds are freely expressed, but that, with few exceptions, reasons for these opinions are not stated.

The first geologist to describe the region was Vanuxem,* who points out that the accordance of the strata on the two sides of the valley precludes faulting, and that a subsidence of the bottom is too extravagant a supposition. He says:

"The lakes to the south of Helderberg range are an important and interesting feature of the district, furnishing facts to show that the excavation of those at the west end of the district (Cayuga, et cetera) was anterior to the dip of the rocks, et cetera. . . . *The whole of these lakes differ in no respect from the long parallel north and south valleys of the same section, but in depth of water and apparently greater depth of excavation.*" †

Being puzzled by the presence of rolled stones from the north, he concludes that the original flow was to the south, but the height of the divide seemed to preclude that. He therefore concluded that the excavation was accomplished before the dip was given to the strata.

Vanuxem's discussion of the lakes ends with this remarkable truism, which deserves to be kept prominently before the mind in all investigations:

"Whatever be the real facts as to the flow of waters in opposite directions, patient investigation in time, if true, will harmonize their results; for truths only apparently conflict with each other, the real conflict being solely in the minds of those occupied with them."

Dr Hall, speaking of the same lakes, says: ‡

"The valleys of Seneca, Cayuga and Crooked lakes, Canandaigua lake and others, are of nearly equal width from one extremity to the other, with nearly perpendicular banks above the water. It seems hardly possible that such channels could be excavated by the advancing and retiring, waves upon a coast which was gradually emerging from beneath an ocean."

The same author says: §

"They (the lakes) are all situated in valleys of erosion; the rocky strata, with a slight dip to the south, appearing on both sides."

One of the first to describe the geology of the Great lakes after the glacial hypothesis had become fairly well established was Dr Newberry, and, although his descriptions were not of the region immediately in

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* Geology of New York, Third District, vol. iii, 1842, p. 237.
† The italics are not in the original.
‡ Geology of New York, Fourth District, vol. iv, 1843, p. 321.
§ Ibid., p. 405.

hand, it seems well to state his views, since they are exactly those to which we are driven by recent studies. While his conclusions seem correct, his reasons were not convincing, as will be seen by an examination of the following pages, in which the opinions of later students are given. He says,* Ontario and the other lakes—

"are excavated basins, wrought out of once continuous sheets of sedimentary strata by a mechanical agent, and that ice or water, or both."

Again he says: †

"No other agent than glacial ice, as it seems to me, is capable of excavating broad, deep, boat-shaped basins like those which hold our lakes."

Essentially these conclusions are repeated by this author in other publications, both earlier and later.‡ In one of them § he says:

"I had claimed the existence of an ancient river flowing from Lake Superior through the lake basin and down the Mohawk valley into the trough of the Hudson, and thence to the ocean by New York. The valley of this stream, locally expanded into boat-shaped basins by glacial action, according to my view, formed the basins of the Great lakes."

Simonds || shows that there are in this region two classes of valleys—gorges, "true valleys of erosion," and rounded, smoothed valleys. Of the latter he says:

"Noting in addition (to their even slope) the depth at which the water flows, and the small number of cascades and waterfalls, the conclusion is at once reached that these valleys have been acted upon by some agency not now in operation."

He can easily understand the gorges, but cannot explain the broad valleys by erosion, and therefore concludes that "these deep, well worn valleys are undoubtedly the result of glacial action." According to this author, the glacier divided near the present site of Ithaca, one lobe moving southward, the other carving out the valley of Six-mile creek.

This, which seems to be the first statement of the glacial origin of Cayuga valley, is based upon the inability of the author to conceive of the formation of a broad, deep valley by river erosion and transportation. It seems strange that he should not have noticed that this valley was but one of a type which exists in that region with directions varying through all degrees of the compass, and hence that all are not capable of explanation by glacial erosion.

* Geological Survey of Ohio, vol. ii, 1874, p. 72

† Geological Survey of Ohio, vol. ii, 1874, p. 74.

‡ Proc. Boston Soc. Nat. Hist., vol. ix, 1862, pp. 42–46; Annals New York Lyceum Nat. Hist., vol. ix, 1870, pp. 213–234; Proc. New York Lyceum Nat. Hist., vol. ii, 1874, pp. 136–138; Proc. Am. Phil. Soc. vol. xx, 1882–'83, pp. 91–95; and elsewhere.

§ Proc. Am. Phil. Soc., vol. xx, 1882–'83, p. 93.

|| Am. Nat.. vol. xi, 1877, pp. 49–51.

Foote* adopts very nearly the same line of argument, stating that he will not consider "whether the glacier or iceberg theory is the more probable," although he believes that both agencies were employed. He believes that the valleys were made into fjords by wave action when the land was elevated, and that they had an outflow to the south. These valleys "were probably much deepened by the gouging action of the lobes of the general ice-sheet which flowed down their channels."

Writing in 1880, Carll† says of the Great lakes, and presumably also of these lesser lakes, that "the basins of the Great Lakes were formed by the widening and deepening of old river valleys through the agencies of ice and sub-glacial water." Shaler,‡ following Ramsay, says "the lakes of Switzerland, [and] those of New York and New England, are good and familiar instances of this work"—glacial erosion.

On the other hand, Spencer§ arrives at the opposite conclusion, for he says:

"Though the bottoms of these lakes (Finger lakes) are frequently below the sea level, yet in no case, that I am aware of, are they nearly as deep as lake Ontario. Doubtless these small lakes were former expansions of the rivers running into lake Ontario in Preglacial times, and owe to ice, simply, the closing of their outlets by drift."

Professor Davis|| partly agrees with Spencer, and writes of lake Cayuga as follows:

"Its trough was cut by an old stream flowing from the New York and Pennsylvania plateau, northward into lake Ontario, at a time when the drainage of the region ran in channels considerably below present river-levels; glacial erosion has probably smoothed and deepened it, but to suppose it entirely so formed would imply the production of a tongue of ice from the front of the old glacier, peculiar in form and remarkable in erosive power; the supposition that it is the result of down faulting or local subsidence, is negatived by the absence of disturbance in the neighboring hills; to call it a rock basin is entirely unwarranted, for its prolongation north of the lake is across a great drift-area, without rock in place. The form of the trough is different in no important particular from valleys of evident erosion in non-glaciated regions."

In the next descriptions we find the opposite view stated, and in this connection Johnson¶ says—

"That these lake basins were excavated by glacial action, seems almost self-evident, and is, indeed, almost universally admitted. Their radiated arrangement,

* Notes upon the Geological History of Cayuga and Seneca Lakes, 1877.

† Geol. Survey of Pennsylvania, III, 1880, p. 331.

‡ Illustrations of the Earth's Surface, 1881, p. 52.

§ Proc. Am. Phil. Soc., vol. xix, 1881, p. 333.

|| Proc. Bost. Soc. Nat. Hist., vol. 21, 1882, p. 359. Professor Davis has a very important paper on "Glacial Erosion" in the next volume, 22, pp. 19-58, in which the subject of rock basins is discussed on page 50.

¶ Annals New York Acad. Sci., vol. ii, 1882, p. 260; see also Trans. N. Y. Acad. Sci. vol. i, 1882, p. 78.

in my opinion, admits of but one explanation, namely, that they were cut by one and the same great glacier, whose margin was broken into several streams in crossing the mountain ridge," * * *

One of the first descriptions of the region from the standpoint of the modern school of glacial geology is by Chamberlin,* who, after describing the region, says:

"That these troughs were the preglacial channels of streams does not seem to me to admit of reasonable doubt; but that there was a *selection* and moulding by glacial corrasion seems equally clear, those channels that lay in the directions that would have been pursued had the ice moved on a uniform floor, being ground out wider, deeper, straighter, and smoother, while those in transverse directions were measurably filled and obscured. The whole region shows, in the most beautiful manner, the subduing, softening effects of glacial grinding and deposition, without the obliteration of the bolder features of the preglacial configuration."

This is almost exactly the view presented in the present paper and by Lincoln and Brigham, as stated below; but Chamberlin's statement is a broad generalization, based upon a survey of the entire field, and is not supported by definite proof that this is the actual interpretation of the history of the region.

Spencer,† writing in 1890 of the lake region of New York, is unshaken in his old opinion that they are no more than river valleys. He uses the fact that the bottoms of these lakes and of Ontario are below sealevel as evidence of a preglacial elevation and postglacial depression of the land, and Upham, in the same volume,‡ refers to this point as proof of the same alternation of level.

Wright also agrees with these authors, and says: §

"Probably, however, they (the Finger lakes) are not due in any great degree to glacial erosion, but they seem to occupy north-and-south valleys, which had been largely formed by streams running towards the St. Lawrence, when there was, by some means (probably through the Mohawk River), a much deeper outlet than now exists, but which has been filled up and obliterated by glacial *débris*. The ice movement naturally centered itself more or less in these north-and-south valleys, and hence somewhat enlarged them, but probably did not deepen them. The ice, however, did prevent them from becoming filled with sediment, and on its final retreat gave place to water."

An important stage in the history of the development of opinion concerning the origin of the Finger lakes is reached by the publication of a paper by Dr D. F. Lincoln in 1892.* Hitherto opinions based upon general considerations have been freely expressed, but nothing definite

* Third Ann. Rep. U. S. Geol. Survey, 1883, p. 358.

† Bull. Geol. Soc. Am., vol. 1, 1890, pp. 65–70.

‡ Bull. Geol. Soc. Am., vol. 1, 1890, p. 567.

§ Man and the Glacial Period, 1892, p. 94; also the same conclusion is reached in Wright's Ice Age, p. 323.

has been evolved. There are two opposite schools, one holding that the lake valleys are merely river valleys clogged with drift, the other school that they are river valleys enlarged very appreciably by glacial erosion. Spencer, Davis, Upham and Wright hold that the former is the case, while Newberry, Carll, Shaler, Johnson and Chamberlin believe in the hypothesis of ice erosion.

That the basins are not entirely ice worn is proved by the presence of the large number of preglacial tributaries flowing in all directions. It is not strange that this, taken in connection with the general form of the lake valleys and their resemblance to mature valleys outside of the glacial belt, should have led those who have taken a cursory glance at the region to conclude that the lakes are merely drift-dammed rivers. This is the more natural since the pendulum of opinion has of late years been swinging away from the belief in glacial rock basin erosion, as the result of the fact that so few definite instances of this kind of work have been absolutely proved, notwithstanding that the theory has been before us for thirty years.†

In his article on the Finger lake region Dr Lincoln‡ says:

"From considerable examination of the country included between the four larger lakes, the writer has been led to set a moderate estimate upon the amount of drift, and a very high estimate upon the amount of erosion in certain parts."

He states that in the cliff, which extends for 20 miles south of Aurora on the east side of lake Cayuga, there are undulations, barely disappearing beneath the surface of the lake, which appear to represent undulations in the old surface. He says: §

"If the lake were drained, the present mouths of the brooks flowing in these hollows would be a mile from the main stream which presumably, occupied the axis of the valley. In going this mile they would fall from 300 to 600 feet. . . . The inference from these considerations is that the preglacial river which has been developed into Seneca lake must have occupied a level many hundreds of feet above the present bed of the lake." ‖

After stating that rock was found in Geneva, at the northern end of lake Seneca, at a depth of 240 feet, Dr Lincoln says: ¶

"A valley three miles wide between existing rock exposures, and 300 feet deeper than the present lake surface, apparently opening to the north, is indicated at Geneva: some of this depth may be ascribed to glacial action."

* Am. Jour. Sci., vol. xliv, 1892, pp. 290–301; Dr Lincoln read a paper upon the same subject before the 1893 meeting of the American Assoc. Adv. Sci., which the author has not seen. See bibliography.

† Ramsay: Quart. Jour. Geol. Soc., vol. xviii, 1862, p. 185.

‡ Am. Jour. Sci., vol. xliv, 1892, p. 297.

§ Am. Jour. Sci., vol. xliv, 1892, p. 298.

‖ Ibid., p. 299.

¶ Ibid., p. 301.

Brigham, in a very excellent description of the region, arrives at the same conclusion that Dr Lincoln has reached. He says:*

"To review briefly, we suppose the basins to be a composite resultant of valley erosion, glacial scoop and drift barriers, with perhaps a slight element of orography."

## Observations and Interpretations.

*Evidence of buried Valleys.*—Coming from a field where the evidences of extensive glacial erosion are limited, and, indeed, where there is distinct evidence of slight erosion, the author attempted to employ the results of his New England experience in the interpretation of the history of lake Cayuga. Thus, while nearly every day he looked upon distinct evidence that the basin of the lake is rock-walled, he did not see the evidence, but was blinded by the simulation of preglacial, mature valley forms.†

The evidence upon which the title of this paper is based is of two kinds, that of the buried channels in the cliff side, such as those referred to above as described by Dr Lincoln, and the evidence of some of the larger streams which are tributary to the lake, and which flow in preglacial rock valleys above the present lake surface.

The cliff above referred to is on the eastern shore of lake Cayuga. The rock surface rises and falls, with gentle slope, into a series of undulations of alternating hills and valleys, the latter in no case extending more than a few feet between the lake surface. They are partly, in some cases completely, filled with drift, and, excepting where revealed in cross-section at the lake shore, are not visible in the topography. They certainly seem to be river-formed valleys, and, taken in connection with the other proof, it seems evident that, as Dr Lincoln suggests, they really are. Aside from the valley in the cliff south of Aurora, described by Dr Lincoln, there are others at various points, one of which shows particularly well on the lake shore about midway between Ithaca and Ludlowville.

*Evidence of Salmon Creek.*—About six or seven miles north of Ithaca, upon the east side of the lake, there is a tributary to the lake, known as Salmon creek, upon which is situated the town of Ludlowville. The creek flows in a broad, mature valley, distinctly preglacial in type, which extends nearly southward and joins the lake at an angle of 20° or 30°. As in the case of all the valleys, except the postglacial gorges, the hills

* Bull. Am. Geograph. Soc., vol. xxv, no. 2. 1893, p. 16.

† While the facts in this article are very nearly of the same kind as those put forward by Dr Lincoln, the author discovered them entirely independently. At the time Dr Lincoln's paper was published I was so strongly convinced that the valleys were river valleys, unmodified by ice, that his paper produced no impression. It was only when the clearness of the evidence impressed itself so forcibly on my mind that I could not but be convinced that I again looked at his paper, and found that he had the same kind of proof. Therefore, although independently worked out, the facts in this article are merely confirmations of his studies and deductions.

rise gradually on either side to the plateau level, many hundred feet above the lake. In the valley bottom there is a drift accumulation, with a depth of a hundred or more feet, through which the stream has cut to the rock beneath.

On the lake shore and in the side gorges the shale can be traced in outcrops with practical continuity to the mouth of this valley on eithe side, so that the preglacial continuation of the valley is not buried beneath drift in the present hillside. There is no gap in the series of outcrops with a width of more than 200 yards.

Without considering whether the lake valley bottom may not have dropped down, I see but three possible explanations of this phenomenon. Possibly the river bottom may be in one of these narrow gaps. Aside from the improbability of a mature stream being suddenly transformed to a narrow, young gorge at the very point where there happens to be a drift deposit, the evidence in Six-mile creek, and in the buried channels just mentioned, is against this; and it might also be asked, where are its coun-

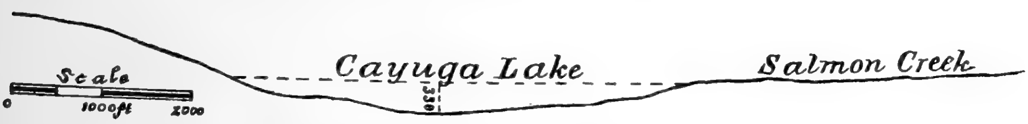


FIGURE 1.—*Cross-section of Lake Cayuga Valley opposite Salmon Creek.*
Vertical and horizontal scale the same.

terparts, for such a condition would necessarily be widespread, not local. A second theory may be that the lakeward continuation of the stream (figure 1) was marked by a fall of 350 feet in less than a mile, notwithstanding the fact that the normal fall is but a few feet to the mile. This is so extremely improbable that it may be dismissed. The third theory is that the north and south valley has been ice-worn, while the tributaries stand at their preglacial elevation, except in so far as they are drift-filled.

Opposite Salmon creek the lake has a depth of 330 feet. The valley of the creek is a rock-bottomed valley of mature type, distinctly not postglacial, but of the usual type of this region; and the rock bottom of this valley is about 20 feet above the present lake surface. We can, I think, assume that this valley, which is transverse to the ice motion., was not sensibly deepened, probably not deepened at all, but always more or less clogged with drift, as it was when the ice disappeared. Consequently we have here approximately the true level of preglacial Cayuga river. It was 20 feet or thereabouts* above the present level of the lake surface,

* The observation in Salmon creek is not exactly on the lake shore, and the channel of Cayuga river may have been on the western margin of the valley; hence this elevation is liable to an error of a few feet.

or 350 feet above the present lake bottom at this point, and 455 feet above the deepest point in the lake.

*Evidence of Six-mile Creek.*—At the head of the lake, in the city of Ithaca, the valley divides—one part, known as the Inlet valley, continuing southwestwardly and then southerly; the other, called Six-mile creek valley, extending in a southeastern direction. The latter is evidently a tributary to the former, which was the preglacial main valley. These two valleys are the ones which Simonds* and Foote † believe to be due to ice action. They are both distinctly preglacial in form, and are joined by mature tributaries.

These two creeks, in conjunction with two others, Fall and Cascadilla creeks, which are diverted streams, flowing near their mouths in postglacial gorges, have constructed the delta-flat upon which Ithaca is built. I am unable to state the depth of this delta, but it appears to be deep, and may have a depth of 200 or 300 feet. At present the Inlet and Six-mile creeks flow through it.

A practically continuous rock outcrop of shale can be traced from a point a half mile north of this valley to an equal distance on the southern side. The valley is even more distinctly rock-inclosed than that of Salmon creek, and the lowest point is fully 50 feet above the lake level, and probably more.‡

These are the only two large stream valleys that have been examined, but either one of them taken alone would be sufficient proof of the point. They have been practically undisturbed by glacial erosion, although clogged with glacial drift, and the present rock bottom is essentially the preglacial valley bottom; it certainly was not lower, although it may have been higher. The north and south valley of lake Cayuga is several hundred feet below it, and its depth has without question been caused by glacial erosion.

*Conditions favoring Formation of Rock Basins.*—The author does not feel that there is a necessity of supporting the above conclusions by an explanation of the manner in which the ice performed its work of basin erosion, for he believes that the facts upon which these conclusions are based are sufficiently definite to warrant their acceptance; but, being a recent convert to the rock-basin theory of lake formation, and knowing the difficulty which he had in convincing himself that the facts were as stated, he wishes to point out that the conditions here are unusually favorable for the formation of rock basins, as well as for their discovery. If, under favorable conditions, rock basins can be formed by glacial erosion, who shall say

* Am. Naturalist, vol. xi, 1877, pp. 49–51.

† Notes upon the Geological History of Cayuga and Seneca Lakes, 1877.

‡ It is difficult to state exactly the elevation, because the stream is locally diverted by the drift filling of the old valley; but I have preferred to give the minimum.

that the extreme believers in this form of glacial erosion are not nearer the truth than those who, like the author, have been inclined to doubt the power of the ice in this direction?

Since beginning this study it has occurred to me to question whether, as in my own case, the term rock basin has not implied mentally more than it does in reality. In cross-sections and longitudinal sections of lakes having a depth of several hundred feet the depth is greatly exaggerated. Lake Cayuga, for instance, in the scale adopted by the engineering department of Cornell University, has a depth of more than two inches, while in reality it should be, on the horizontal scale adopted, only a slight bulging of the lower part of a line. On the scale used in that map, if the vertical scale were the same as the horizontal, as it appears to be at a glance, the depth of the lake would be nearly four miles.* This same point is brought out by Ramsay for lake Geneva.† Lakes, even deep ones, are therefore mere scratches when compared with the mass of ice. Their depth is extremely slight compared with their width and length, and the ice does not have to go down into a deep hole and ascend in order to erode the basin. On the contrary, it needs only to wear irregularly, and, where conditions are favorable, this may be easily done.

In the Finger lake region the ice, moving from the northward, after entering the valley occupied by lake Ontario, found its progress interfered with by the rising New York-Pennsylvania plateau. Naturally the north-and-south valleys furnished lines of easiest escape, and naturally, also, the ice motion was here more powerful and the ice deeper. That the latter was true is proved by the fact that, even without the added depth due to ice erosion, these valleys were, at the beginning of the glacial invasion, at least 700 or 800 feet below the general upland level. This increase in thickness means, other things being favorable, an increase of erosive power. While this of itself is a pure deduction, the facts in the field prove its truth, for at the head of the lake valleys the moraine is thick and extensive, while upon the uplands it is comparatively inconspicuous. Greater deposition means a greater supply, and this indicates more erosion and more motion to bring new supplies.

It is a striking fact that almost all of these lakes have their northern end in the hard Helderberg limestone and their southern ends and deepest parts in the softer shales of Marcellus and Hamilton age. Moreover, the dip is gently southward. Perhaps even without these peculiarities the ice might have eroded a rock basin; but cetainly this soft, crumbly, thin bedded and well jointed shale, dipping away from the

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* Brigham: Bull. Am. Geograph. Soc., vol. xxv, no. 2, 1893, p. 15.

† Physical Geology and Geography of Great Britain, fourth edition, 1874, p. 170; Quart. Jour. Geol. Soc., vol. xviii, 1862, p. 185.

direction from which the ice moved, must have aided in increasing the depth.

Chamberlin,* in discussing the possible southerly continuation of the preglacial Cayuga river, points out a fact which, in considering the erosive power of glaciers, is of much importance. He shows that to obtain a great accumulation of drift we must have great erosion, just as in the case of railroad construction cutting must be made before filling. He therefore considers that it is more conservative to hold that there is considerable erosion and considerable filling than that there is practically no erosion and vast accumulation. The mass of morainic drift at the head of Cayuga valley indicates much erosion, and Chamberlin was the first to point this out, although few seem to have understood the imporance of the conclusion. He says:†

> "It seems to the writer, therefore, quite clear that the assumption that involves the least glacial corrasion is not that which denies to ice any notable action in the modification of the topography of the rock surface, but rather that which assumes that the rock prominences were ground down and some of the great channels of flow excavated, while the remaining depressions were filled with the *débris.*"

*Rhythm of Deposition and Erosion.*—It is a striking fact in this region, and one which the author has noticed elsewhere, in parts of New England, that near the ice margin there is a rhythm of ice-work; that is to say, there is an alternation of erosion and deposition. On a small scale there is the same phenomenon illustrated in drumlins, whether we explain them by one or the other of the two most probable theories. Like a series of waves with trough and crest, the ice appears to move, or perhaps better, like the meandering river, depositing at one point and eroding at another with a rhythmic curve of repetition. In the valley of lake Cayuga there is a moraine at the south, then a zone of rock excavation, followed to the northward by extensive deposition (or comparative freedom from erosion) ‡ in the form of parallel drift hills of drumlinoidal outline, and again, I believe, by extensive erosion in lake Ontario basin. What is the explanation of this? Is it universal? This rhythm of glacial work impressed itself upon the mind of the author in New England, where much less developed, and here in central New York it appears to be illustrated in almost ideal perfection.

*Northward Flow of Cayuga River.*—Was the direction of flow of this preglacial Cayuga river northward or southward? Chamberlin § says upon this point—

* Third Ann. Rep. U. S. Geol. Survey, 1883, p. 356.
† Third Ann. Rep. U. S. Geol. Survey, 1883. p. 356.
‡ Johnson: Trans. N. Y. Acad. Nat. Sci., vol. i, 1882, pp. 77–80.
§ Third Ann. Rep. U. S. Geol. Survey, 1883, p. 355.

"It has been a somewhat current assumption that this valley, in common with the adjacent ones, is an old river trough that discharged southward through the Susquehanna. If this be true, and no allowance be made, on the one hand, for drift deposits in the bottom of the lake, nor, on the other, for glacial corrasion, the total depth of the drift under the crest of the moraine must exceed 1,000 feet, and this depth, approximately, must continue far down the Chemung-Susquehanna valley."

Now that much of the depth of the lake is proved to be due to ice erosion this loses some of its force, but even now the depth of drift must needs be nearly 600 feet, which of itself is almost incredible. There are, however, abundant and sufficient reasons to show that the river course was north and not south. In the first place, the divide itself has every appearance of being a preglacial divide, modified only slightly by glacial deposits. It is doubtful if these deposits reach to the height of the preglacial divide.

Moreover, the general plateau slope is from south to north, and this is evidently a preglacial slope. Of even more importance than this is the fact that in the present head-water region there is a comparatively accented topography, which, though still mature, is strikingly more diversified than that to the north. Gradually the main valley and the preglacial tributary valleys lose in height toward the north, and near the present lake outlet the valley walls retreat, on either side, as a very even, gently undulating escarpment. These conditions, since they are preglacial, seem to prove that the flow was northward, and very few competent observers have doubted this.

Since this point is of vital importance to the remainder of the argument, and is the one upon which most dependence is placed, I will, in order that its full significance may be seen, restate it, even at the risk of repetition. Cayuga valley is a preglacial valley enlarged by ice erosion. Being preglacial, it shares with the other similar valleys of this plateau the mature form or habit. A mature valley has a more accentuated topography near its head than near its mouth. In the latter portion it is broad, the valley sides are low, and the tributaries enter through valleys which, near their mouths, are shallow. As the head-waters are approached the valley walls become steeper, nearer together, and the tributaries enter through deeper and narrower valleys than those near the mouth.

This is a fundamental principle of river development, provided there has been nothing to interfere. There appear to have been no immediate preglacial accidents in this valley, and the rock throughout its length is sufficiently uniform to warrant the statement that these conditions must be looked for in all the mature streams if they occur in one. Upon the line of this argument, therefore, if we find the valley becoming

less accentuated toward the north and the tributaries entering through shallower valleys, the assumption is warranted that this is the direction of flow. In lake Cayuga valley, as is stated in the first section of this paper, this is the case in the northern end. This argument of itself seems to me conclusive, and the others are introduced merely as confirmation.

But, if more proof is needed, we may point to the preglacial tributaries of Cayuga river. Six Mile creek, about a mile and a half from the head of the lake, had its preglacial channel about 50 feet above the present lake surface; Salmon creek, seven or eight miles farther northward, flowed at an elevation of about 20 feet above the present lake-level, and the valley near Aurora had its level slightly below the level of the lake. There is, therefore, as indicated by the tributaries, a constant river slope toward the north.

*Evidence that Lake Ontario is a Rock Basin.*—It seems to me that we may fairly conclude that the direction of flow of Cayuga river was northward. It was, then, in all probability, tributary in some way to the stream which passed through the valley of the present Lake Ontario, which is but 40 miles distant; but at present the surface of this lake is

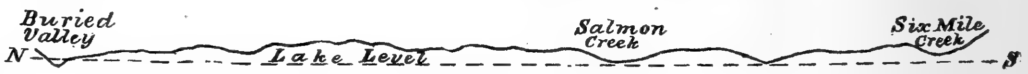


FIGURE 2.—*Preglacial Valley, Cayuga Lake.*

Exaggerated vertically to show the northward slope of the preglacial Cayuga river as indicated by the tributaries.

246 feet above sealevel and the bottom 738 feet below the surface, or 492 feet below sealevel. Is it possible that Cayuga river, a mature stream with a gentle slope for a distance of 40 miles, should, near its mouth, so increase its slope as to fall about 800 feet in the distance of 40 or 50 miles? Is it not, rather, that Cayuga river flowed with the normal slope and entered a river whose channel was not below the present surface of lake Ontario, but, on the contrary, above it?

Here the inquiry naturally arises as to whether the foregoing facts do not indicate that lake Ontario is also a rock basin?

It may seem that this is not a warranted conclusion and, indeed, it is put forward only tentatively, as a suggestion, in the hope that it may stimulate some one to look for evidence of the same nature as that used in the discussion of the origin of Cayuga. There may, it is true, be a complication of rock-folding which shall make the problem of the origin of lake Ontario less simple.

The evidence seems to the author to be very suggestive. A series of valleys extend toward lake Ontario and reach a point only forty or fifty miles distant, the intervening area being a drift-covered plain. Cayuga

at least, and presumably the others also, had a north flow unless I have entirely misinterpreted the value of the evidence. The mature valleys of the upland tributaries to this main stream had a moderate slope, if we may judge them by their present condition, as seems to me justifiable. The evidence of the mouths of the preglacial tributaries brought forward in figure 2 suggests also a moderate slope. The indications are, therefore, that this was the case also beyond the outlet of the present lake in the old valley now buried beneath the drift. Even granting that this river had a very irregular course, it must, provided a deep valley passed through the site of the present lake Ontario, have had an extremely rapid slope, much more rapid than would be expected in a mature stream; and the diagram (figure 1) might then be used for lake Ontario, substituting the name Cayuga river for Salmon creek, and lake Ontario for lake Cayuga, and at the same time changing the scale. It therefore seems unlikely that it did have this slope, but that the slope which appears to be necessary has been caused by glacial erosion.

It is interesting to note in this place that, just as in the case of lakes Cayuga and Seneca, lake Ontario has its greatest depth on its southern side, and that the deepest point of the lake is just north of Cayuga and Seneca, where the greatest glacial erosion in the Finger lake region is accomplished.

If the above conclusion be true, then we have no proof that the interior of the continent in this region has been depressed since the glacial period, nor that it was higher in preglacial times.

## Summary.

Briefly summarized, this paper, after a description of the topography of the region and a summary of the opinions previously held, attempts to prove that lake Cayuga, and presumably other of the Finger lakes, is situated in a rock basin with a maximum depth of approximately 435 feet. The nature of the proof is that the preglacial tributaries to this valley are found to be rock-enclosed, and that their lowest points are above the present lake surface.

It presents also a brief discussion of the reasons why a rock basin was constructed with comparative ease in this region; and a rhythm of glacial erosion and deposition is suggested. The course of the preglacial Cayuga river is found to be northward, probably tributary to a river which drained at least one of the Great lakes, Ontario. As the tributaries of Cayuga river prove the rock-basin origin of lake Cayuga, so also the Cayuga river tributary to the Ontario stream indicates, that lake Ontario is also a rock basin.

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Since the above was written Professor Lincoln has published another and very valuable paper upon this subject, in which additional points are brought forward. The paper is entitled: "Amount of Glacial Erosion in the Finger-lake Region of New York."*

*Am. Jour. Sci., vol. xlvii, February, 1894, pp. 105–113.

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# PRE-PALEOZOIC DECAY OF CRYSTALLINE ROCKS NORTH OF LAKE HURON

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(*Read before the Society December 28, 1893*)

CONTENTS



## RELATION OF ARCHEAN TO PALEOZOIC ROCKS.

In all parts of Canada where the Paleozoic strata come in contact with the underlying Archean rocks the latter appear to pass beneath them with very much the same contour or slope as that of their modern surface. It appears evident that these ancient stratified or laminated rocks have been tilted to their present high angles, and that their included intrusive masses, whether of granite or greenstone, and even most of their dikes, have occupied their present positions relatively to each other before the commencement of Paleozoic time, excepting in cases where faulting has taken place. Not only is this so, but at that early date they appear to have been worn down by denudation to something like their present superficial aspect.

What has become of the vast amount of débris resulting from this denudation? This is a problem of American geology which has not

yet received much explanation. Between the time of the folding of the Huronian rocks and the deposition of the earliest fossiliferous beds there must have been an interval much greater than is commonly supposed. Throughout the vast region of Canada occupied by the Archean rocks the attitude of the Huronian and Laurentian strata generally approaches the vertical, and their surface has generally been cut down to nearly a horizontal outline, which is only slightly raised above the sealevel.

Lower Silurian strata, especially limestone, unaltered and full of fossils, may be seen in many places, resting almost horizontally upon the upturned and denuded edges of the crystalline rocks, and yet the former contain but few fragments of the older terranes, and they occur only at the very contact, showing that the latter had a hard and naked surface when the Paleozoic rocks were being deposited upon them.

## Evidence of pre-Paleozoic Decay.

*Where best displayed.*—The evidence of pre-Paleozoic decay of the ancient surface is more discernible upon the surfaces of masses of intrusive granite than upon gneiss or other foliated rocks. The reason of this seems to be that in the bottom of the deep sea, where the eating away of the rocks appears to have taken place, the granite was more susceptible to disintegration than the others. Possibly this susceptibility may have been increased by a somewhat higher temperature in the intrusive granite.

"*Ovens*" *or Pits of Decay.*—The northwestern portion of George island and the greater part of the township of Rutherford, at the northwest extremity of Georgian bay, consist of red granite. Wherever the surface of this rock has been protected from glacial action it is found to be eaten into hollows in the form of round and sack-like pits and small caverns. The latter generally occur on steep slopes or in perpendicular faces of the rock, which, however, do not rise to any great height in this vicinity. The floors of these caverns are usually flat, as they are formed by the lower sides of horizontal joints, while the roofs are arched like ovens. Whatever may have been the agency which excavated these ovens, it always worked inward from the granite face and upward from the floor formed by a joint, the rock of the latter not being affected, but remaining as sound here as elsewhere along the joint-plane.

One of these caverns, which occurs in the western part of Killarney village, opposite to George island above mentioned, and which is shown in figure 1 of plate 15, the reproduction of a photograph, has almost the form and dimensions of the clay ovens used by the French Canadians for baking bread, while other caverns in the neighborhood bear more or less resemblance to this one; hence they have received the local name of

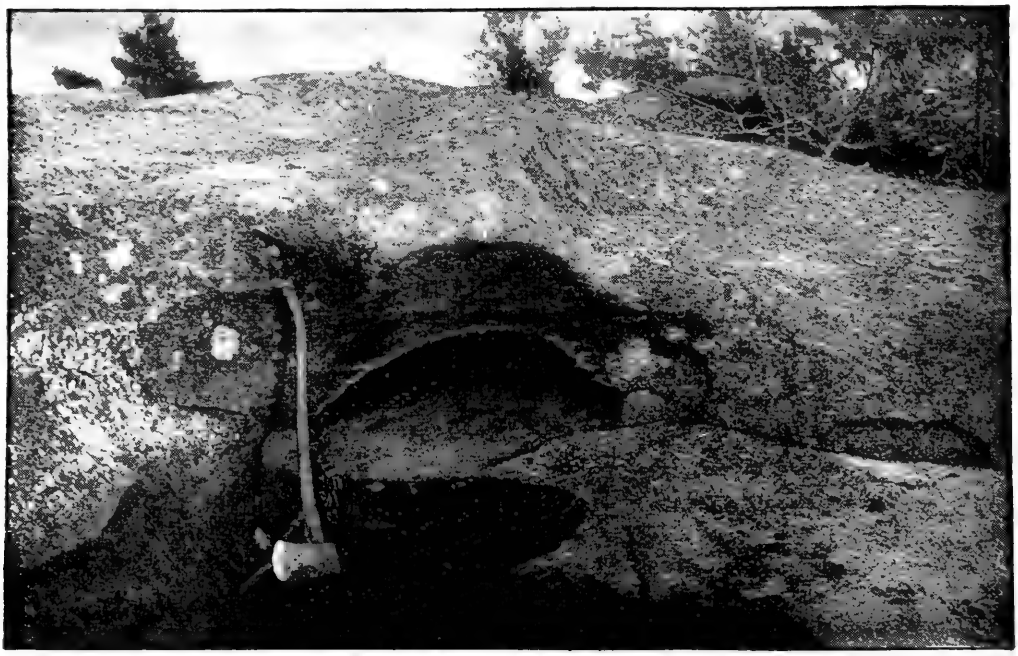


FIGURE 1.—"OVEN" IN GRANITE, WEST END KILLARNEY VILLAGE.

FIGURE 2.—ERODED GRANITE SURFACE AT KILLARNEY VILLAGE.

PRE-PALEOZOIC ROCK DECAY.

"ovens," which may also be adopted for convenience as their geologic designation. The oven shown in this figure measures 5 feet deep, 8 feet wide and $2\frac{3}{4}$ feet high. Two men can crouch inside of it. The door or entrance is 18 inches high and $2\frac{3}{4}$ feet wide, which are also about the proportions of the door of a baking oven of the above dimensions.

The pits, which occur mostly upon the nearly horizontal surface of the granite, differ from glacial kettle-holes in being shallower, seldom quite circular and in having rough walls. The sack-shaped ovens are most numerous upon sloping surfaces. In nearly every case the fundus of these hollows is pointed up-hill, arched over by a roof having a thin edge o rather harder granite than the general mass, and is in the form of a segment of a circle. The granite around these pits and caverns is all bare and exposed to the weather, but it shows no decay or disintegration below the immediate surface. Figure 2 of plate 15, the reproduction of a photograph taken at Killarney village, represents this condition. In some places near by it is partially smoothed and striated, as if the glacier had touched it very lightly and planed off little spots here and there, the fine striæ running south 30° west, but at half a mile to the eastward the granite is completely moutonné and the grooves run south 40° west.

## Rocks of the Huronian Belt.

The portion of lake Huron between the main north shore and the Manitoulin chain of islands is called the North channel. The quartzites, schists, etcetera, of the great Huronian belt, standing nearly on edge, strike very regularly about east and west for many miles along the north shore and through numerous islands of this channel. A few miles west of La Cloche an intrusive mass of red granite, having a nearly circular form and a diameter of about four miles, interrupts the run of the quartzites, etcetera, which, however, continue their regular east-and-west course on either side of it. On Benjamin island the hills in the central part of the granite intrusion rise to a height of 160 feet above lake Huron. Resting on the southern flanks of this island are small areas of Black river limestone near the level of the lake, while larger flat-lying portions of the same formation, constituting Amedros, Clapperton and Hook islands, approach the granite closely to the east, south and west.

## Ancient Erosion.

*Typical Erosion Surface.*—Benjamin island, which is about two miles long, consists of hummocks of granite of various heights up to 160 feet, and these present bluffs toward all points of the compass. In many

places on this island, where the rock surface has been sheltered from glacial action, whether level, sloping or perpendicular, it is eroded into pits, hollows, hummocks and knobs and has a very rough appearance. These surfaces bear a strong resemblance, on a large scale, to the pitted exterior of an aërolite. This is well shown in figure 1, a drawing from a photograph, which represents a granite surface on Benjamin island.

The hollows sometimes take the form of long but not deep caves, undermining the perpendicular faces of steps in the rock which rise at intervals of ten to twenty feet from one horizontal joint to the next above. At other times they are sack-shaped cavities, extending from a few inches to several feet into the rock. As on George island, already referred to,

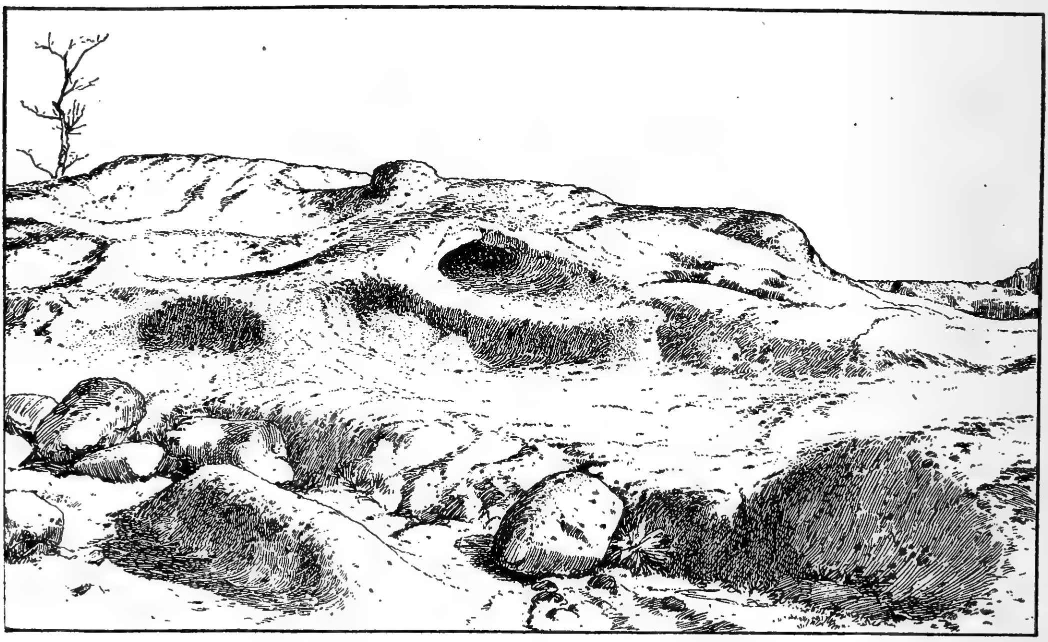


FIGURE 1.—*Eroded Granite Surface near the north End of Benjamin Island.*

this form is very common on steeply sloping surfaces, and in these cases the upper side of each cavern is generally covered with an arch which thins away toward the front (figure 2).

In half a dozen cases observed on Benjamin island, the pits at various heights from the level of the lake up to 100 feet or more were filled *in situ* with horizontal layers of the fossiliferous Black river limestone like that which overlies the granite at lower levels. The limestone entered into all the little irregularities of the pits and adhered firmly to their walls, thus helping to retain its hold in these cavities during the time the present surface has been exposed to the weather. The little patches constitute veritable, if minute, inliers of the Black river formation. The limestone probably originally filled all the inequalities in the granite

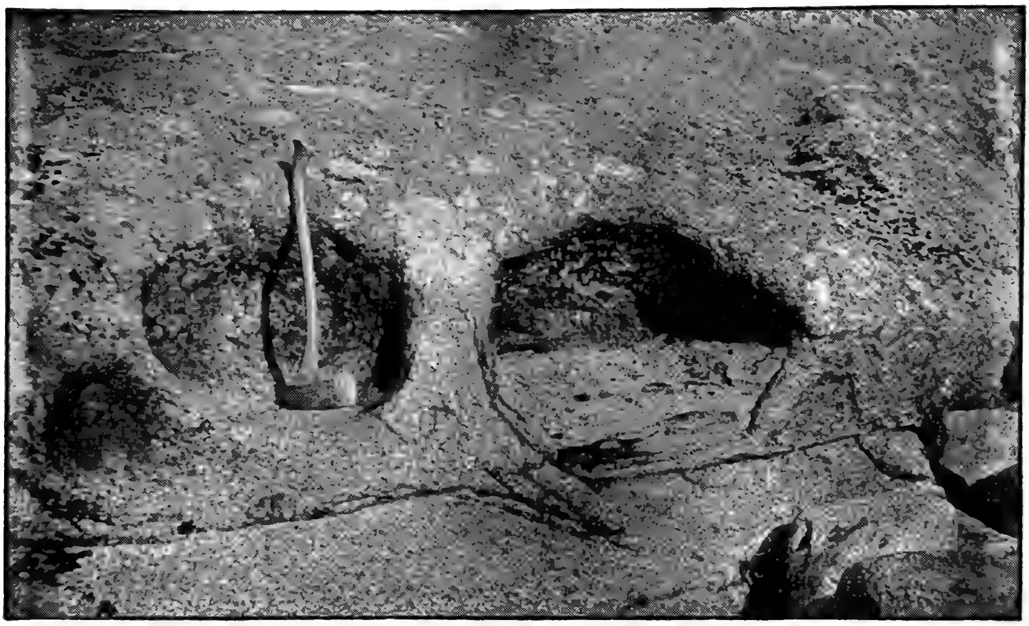


FIGURE 1.—PIT IN GRANITE CONTAINING ARENACEOUS LIMESTONE IN SITU.

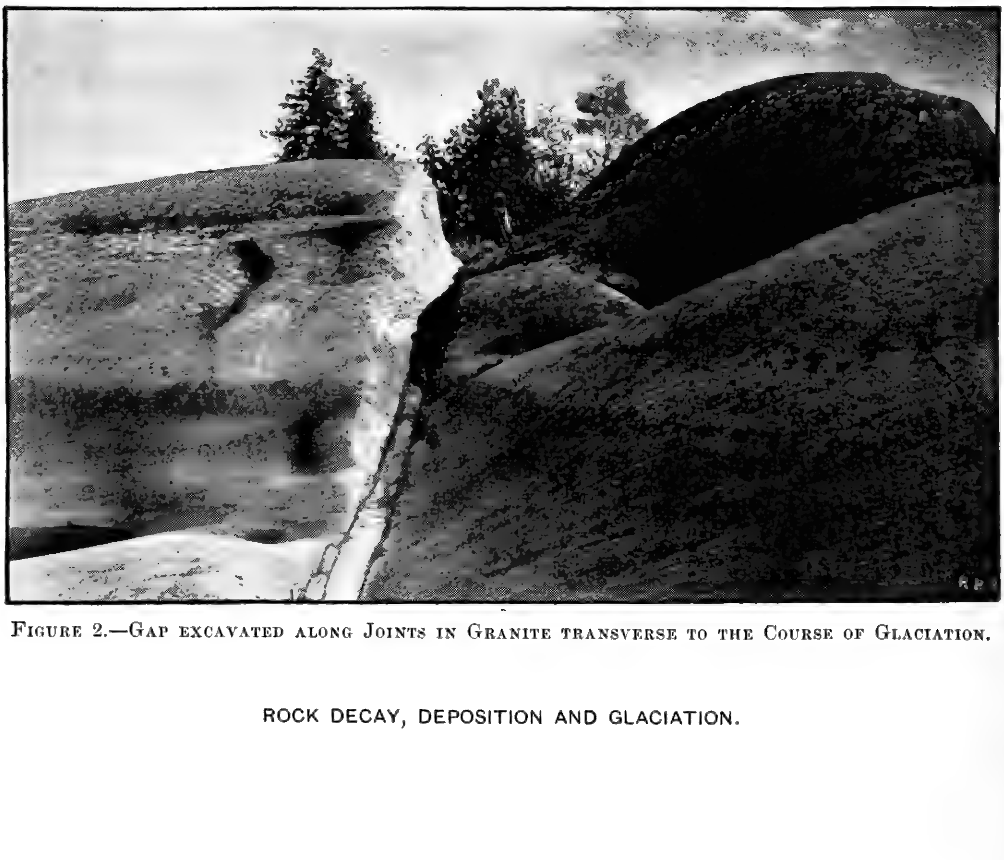


FIGURE 2.—GAP EXCAVATED ALONG JOINTS IN GRANITE TRANSVERSE TO THE COURSE OF GLACIATION.

ROCK DECAY, DEPOSITION AND GLACIATION.

surface on which it was deposited, but along with the great mass of the formation was removed by denuding agencies, mostly prior to the glacial epoch.

Figure 1 of plate 16 represents some arenaceous limestone remains *in situ*, in one of the pits, on a steeply sloping granite surface at the south end of Benjamin island. The eroded surface of the rock on this island also occasionally exhibits curious low, circular ridges three or four feet in diameter and three or four inches in height, weathered out of the granite (figure 3). Each circle is surrounded by a slight depression, while the space within has the form of a very shallow basin with a small mound rising in the center. The granite of the mound and the annular

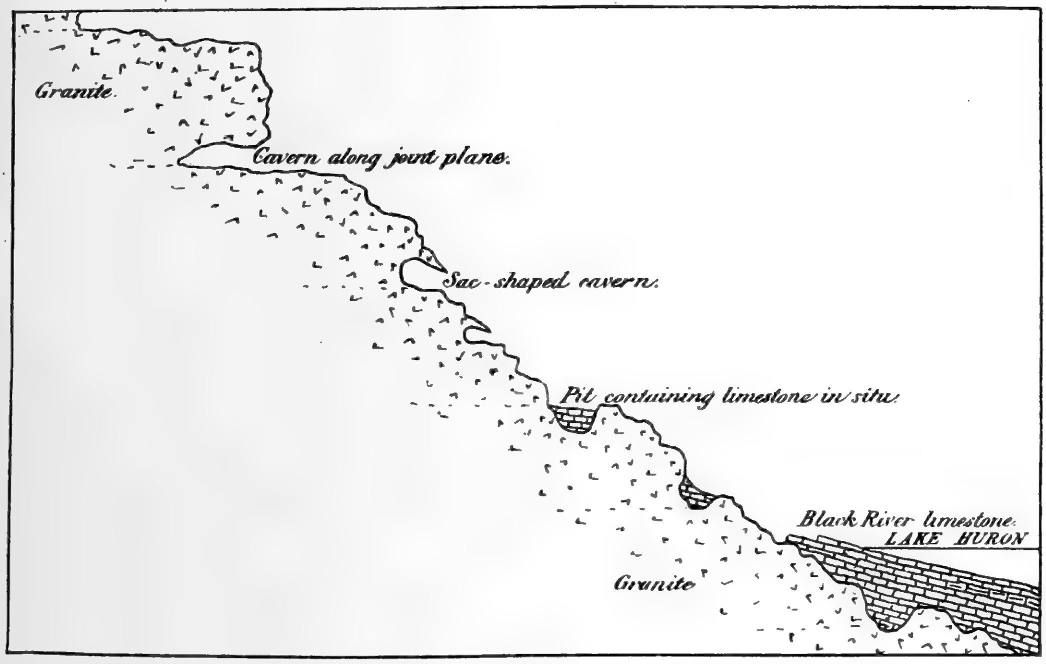



FIGURE 2.—*Section of eroded Surface of Granite with Lower Silurian Limestone resting upon it.*

ridge are rather finer grained than the surrounding mass. They are apparently of concretionary origin.

*Conditions affecting Erosion.*—Under what conditions did the ancient erosion above described take place? The facts above presented, as well as others about to be mentioned, would appear to indicate that it occurred at the bottom of the deep sea, for it is known that rock-surfaces do sometimes become pitted or dissolved under deep water. If this erosion had taken place on land we should have evidence of deeper decay in the substance of the rock, while the subsidence of the land to permit the deposition of the fossiliferous limestone upon it would be indicated by detrital shallow-water deposits, such as sandstones and

conglomerates. The occurrence of pure limestones in the pits and ovens of Benjamin island, in one case in the face of a perpendicular bluff, as well as of the nearly horizontal beds of greater extent upon the sound though uneven surface of the granite, such as might exist at great depths in the sea, but not upon the land, shows that the rock had become thus eroded and was destitute of other covering when the limestone began to be deposited upon it. The sea bottom then rose to a more moderate depth, so that an abundant fauna found a suitable habitat and the formation of the limestone commenced. The area now occupied by the North channel of lake Huron might at that time have formed a quiet arm of the sea, with hills of Huronian rocks to the north, as at present, and similar hills to the south, which have since sunk to lower levels, but of which traces remain.

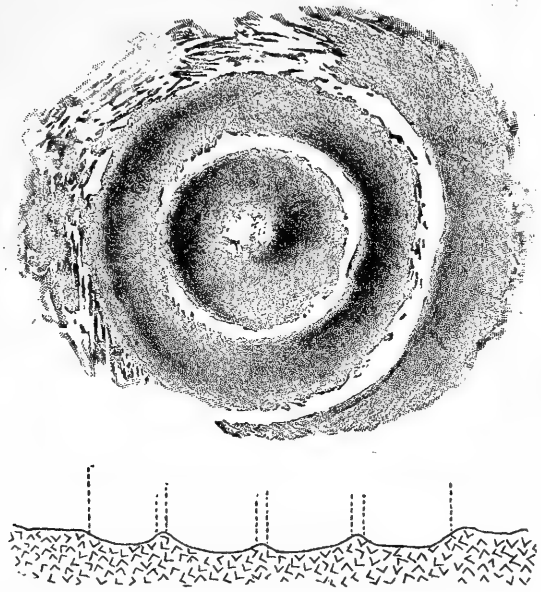


FIGURE 3.—*Low, circular Ridge, four Feet in Diameter, on weathered Surface of Granite.*

## CONTACTS OF ARCHEAN WITH PALEOZOIC ROCKS.

Along the junction of the Archean and Paleozoic rocks occurring between the foot of lake Ontario and the head of Georgian bay the actual contact of the Potsdam sandstone and Black river limestone with the Laurentian gneiss may be seen in a great number of places. The surface of the gneiss, which can be observed to pass under the nearly horizontal beds of the newer rocks, is generally rough or angular, quite hard and fresh looking, as if it had never been exposed to weathering on land. The points and promontories of these flat-lying strata which stretch northward from the general line of the basal geographic boundary of the Silurian rocks in this region lie on the lowest ground or in the orographic depressions of the southern margin of the Archean area, where they found shelter from glacial erosion or preglacial decay. It is doubtful if either these or higher formations ever extended over a large part of the Archean area to the northward, as is commonly supposed, although judging from the vast amount of their ruins which have been carried south they must have been much more extensive before the glacial epoch

than at present. The middle Silurian inlier in the great orographic depression of lake Temiscaming on the Ottawa, which will be again referred to, is another example of these newer and undisturbed strata occupying ground much below the general level of the surrounding country.

On the north shore of lake Huron, between Killarney village and Spanish river, and again on Grand Manitoulin island, in the vicinity of Sheguenda and westward of that village, the Lower Silurian strata rest almost horizontally upon the flanks of bold bare ridges of quartzite, the stratification of which stands nearly vertically. The angles of slope of the ancient rock-surfaces exposed to the weather along the crests of these ridges are continued, as far as can be observed in sections, under the newer rocks forming their flanks, so that the former represent only the upper parts of ridges, once much higher, but now partly buried under the strata which accumulated around them in Silurian times. A high ridge of quartzite runs along the north side of Frazer bay, and a similar ridge, but less elevated, forms the northwest side of Killarney bay. The summits and sides of these ridges are, for the most part, thoroughly smoothed and striated by glaciation, but near their southern bases occasional spots are found which have escaped the action of the ice and which show evidence of great antiquity, the flinty rock being worn into pits and hollows, but with no sign of granular or textural disintegration. A broken fringe of Black river limestone skirts the base of the quartzite range on the northwest side of Killarney bay, and the erosion of the spots referred to may be of pre-Paleozoic date, having been preserved till now by a thin limestone covering, or they may represent portions of the surface as it existed immediately before the glacial epoch which have escaped the smoothing action of the ice, but this is not so likely.

In the neighborhood of the quartzite ridges only those beds of the newer rock which are in contact with the old formation contain angular fragments of the rocks on which they lie. The layers containing this débris are usually of no great thickness and the fragments themselves are of small size; but close to Sheguenda, to the north and south of the village, are pretty thick strata composed of sharply angular pieces of quartzite of all sizes packed closely and confusedly together, with only enough calcareous cement to consolidate them. This locality is about twenty miles south of the main Huronian area left uncovered by Silurian strata and the water of lake Huron.

On La Cloche island and elsewhere in the vicinity numerous ridges and domes of Huronian quartzite protrude through the flat-lying Silurian limestones and shales, so that the former resemble masses which have been forced up through them from below, whereas they are only higher portions of the old sea bottom, around which the horizontal beds

of the much newer rocks were deposited. The quartzites appear to have undergone no change in texture, structural attitude or even surface contour since a period vastly antedating Silurian time. Such facts as these indicate pretty clearly that the physical features of the older parts of our continent had their origin at a very remote period.

### River and Lake Channels due to Rock Decay.

The writer has elsewhere* shown that many of the long, straight valleys in the Archean regions of Canada, now often occupied by straight river stretches, by long, narrow lakes, and by inlets of the larger lakes, are due to the decay and removal of wide greenstone dikes or of parallel dikes, together with the belts of rock between them. When the depressions along these decayed dikes are not overspread by water they form valleys, more or less filled up with drift, so that the greenstone in the bottom may be only exceptionally exposed to view. Copious springs frequently issue from the drift in these valleys.

The long, narrow and straight inlets of the northern part of Georgian bay have had their origin along the courses of dikes of this class. The continuation of each of these channels out into the bed of the lake in front of it is distinctly marked by a straight line of deeper soundings, having the same direction as the fiord itself. Collins, Key, Henvey and Byng inlets, each about twelve miles long, but averaging only 200 or 300 yards in width, are good examples of these fiords. Among the more conspicuous of the long, narrow and nearly straight valleys of the Archean region which have been formed in the manner just described may be mentioned that of Onaping lake, 30 miles long, north of lake Huron; Long lake, 52 miles long, north of lake Superior, and Sepiwesk lake and Nelson river below it, 96 miles long, north of lake Winnipeg. The greenstone of the dike or dikes along the course of these channels may be seen only on islets and points or in patches adhering to the country rock on either side. In the case of Long lake, an immense greenstone dike emerges from its southern extremity and runs into the hills in the same bearing as the central line of the lake.

The course of the Mattagami river, the central branch of the Moose, is guided in its northward trend for a distance of 160 miles from the head of lake Kenogamisse by a number of long dikes of greenstone from 200 to 1,000 feet wide, all having nearly the same direction.† In a typical section of this part of the river we find that the central portion of the dike is coarsely crystalline and more deeply eroded than at the sides and

* Reports Geol. Survey Canada, 1870, p. 331; 1875, p. 315; 1878, p. 15 CC; Report Bureau of Mines Ontario, 1891, p. 76; Bull. Geol. Soc. Am., 1890, p. 300.

† Report of R. Bell: Geol. Survey of Canada for 1875, p. 315.

that it has given rise to the main channel of the stream. The gneiss has been altered and shattered for some distance from the walls of the dike, and this has also suffered decay and erosion and now forms a parallel channel on either side of the central one. Between them the finer grained, hard and undecayed greenstone constituting the outer portions of the dike rises up in the shape of ridges and chains of islands, so that the river flows as a main central channel more or less separated from the smaller lateral ones.

Lake Temiscaming, on the Ottawa, like the Montreal river, which enters its southern extremity, appears to follow the course of a great decayed dike or set of parallel dikes. It lies in a narrow depression which cuts across the general strike of the Archean rocks of the region, and its surface is probably 500 feet below the average elevation of the surrounding country. Its width is only from a mile to two miles, and it has a length of thirty-five miles, but the channel is continued in Deep river, the name given to the section of the Ottawa immediately below it. Temiscaming is an Ojibwé word meaning "deep lake," and it is well named, for in one part it measures, according to Mr A. E. Barlow, 1,800 feet in depth. The bottom is covered very unequally with drift, which has been pushed into it by glaciers at different times, and the deepest part of the bottom may still be a considerable height above the sound greenstone below this filling. If we suppose this height to be 300 feet, then we have a total of 2,600 feet as representing the average height of the surrounding country above the bottom of the excavation. The surface of the lake is 612 feet above the sea, so that the bottom of the water is about 1,200 feet, and that of the whole rock excavation may be 1,500 feet or more below this level. This may, therefore, be regarded as a very deep cutting across a country, the general aspect of which is that of a mammillated plateau with few great inequalities.

The islands toward the north end of the lake consist of limestone of the Niagara formation, which also rises in cliffs at its extremity and extends northward a considerable distance beyond the lake in the same orographic depression, while the Upper Ottawa river falls over the side of this valley by a rapid descent from the plateau to the eastward.

This valley therefore existed before the date of the Niagara formation, and it is probable that under the limestone just mentioned may be found older members of the Silurian system. Greenstone dikes which so frequently cut the Archean rocks of northern Canada have never been found to traverse the overlying Silurian, and we are therefore warranted in supposing that the valleys which mark the courses of the decayed dikes among the former class of rocks were mostly formed before the deposition of the Paleozoic strata.

## Absence of Paleozoic Deposition and its Significance.

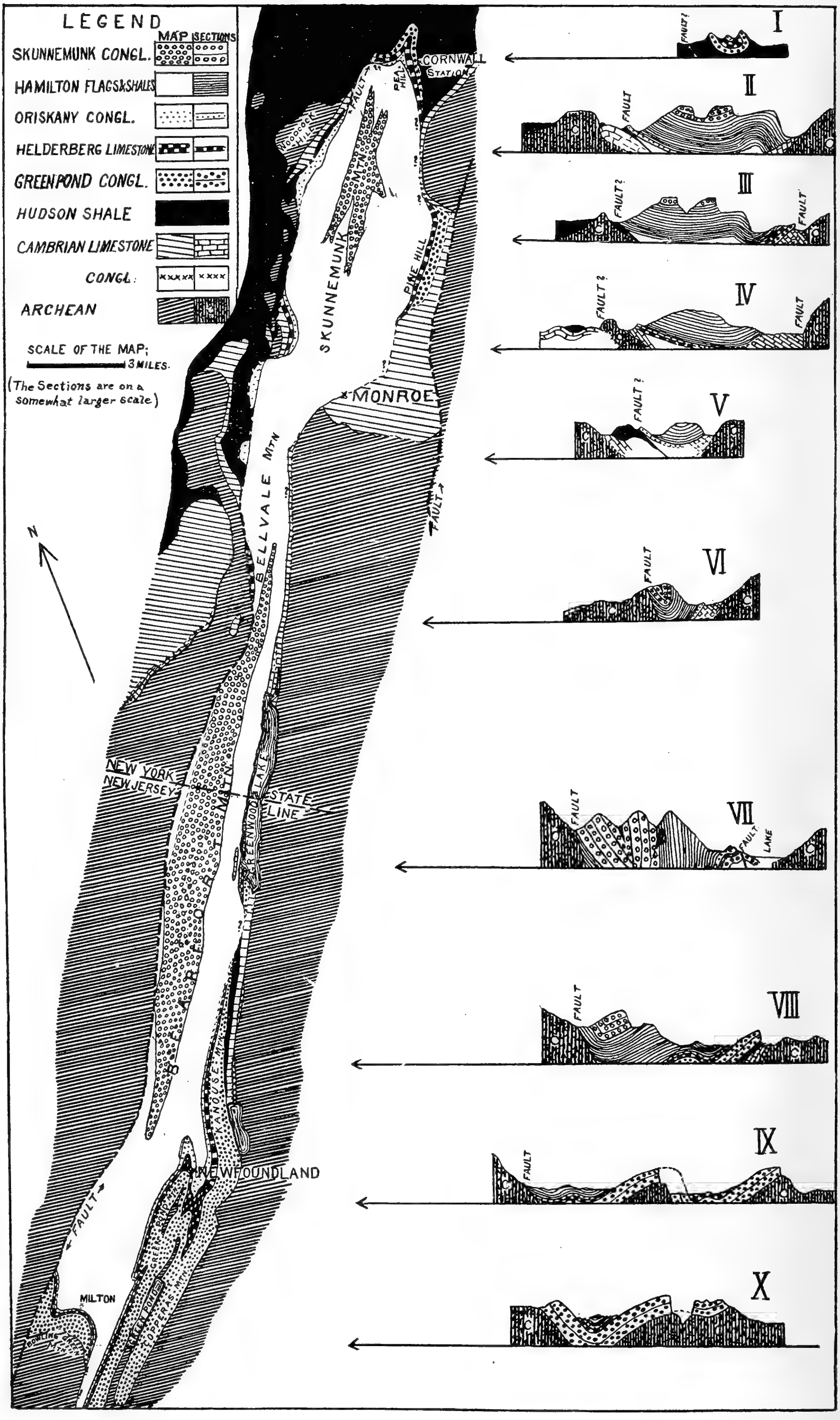
The greater part of the Archean area referred to probably never received any deposit of Paleozoic rocks upon it, so that although numerous long and deep valleys, such as those which have been referred to, existed since an earlier period, no evidence of such rocks may ever be found in the larger number of them.

The depressions already mentioned as filled with outliers and projecting tongues of Potsdam sandstone and Black river limestone along the northern boundary of the Paleozoic formations between Georgian bay and the foot of lake Ontario also go to prove, as we have seen, that the surface of the Archean rocks had been reduced to something like its present level and aspect before these beds were laid upon them.

## Effects of glacial Denudation.

In a former paper* the writer described the effects of glacial denudation in forming valleys and water channels along the courses of ancient lines of crushing and subsequent decay in the crystalline rocks north of lake Huron. A similar effect has been produced in this region, where groups of parallel joints run close together, with a considerable breadth of more solid rock on either side, and where the comparatively thin walls between them have become softened by the long continued penetration of surface water. It is probable that the deep decay along these joints and lines of fracture took place in pre-Paleozoic times. The disintegrated rock along them was removed by glacial erosion with almost equal facility, no matter what their course may have been, even where the resulting channels are narrow and lie transversely to the direction of the excavating force. A good example of this, on a small scale, is shown in figure 2 of plate 16, which is taken from a photograph of a gap in the granite on George island, at the northwestern extremity of Georgian bay.

*See Report of the Ontario Bureau of Mines, 1892.




GEOLOGIC MAP AND SECTIONS FROM GREEN POND, NEW JERSEY, TO SKUNNEMUNK MOUNTAIN, NEW YORK.

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# GEOLOGIC RELATIONS FROM GREEN POND, NEW JERSEY TO SKUNNEMUNK MOUNTAIN, NEW YORK*

BY N. H. DARTON

(*Read before the Society December 28, 1893*)

CONTENTS



## INTRODUCTORY.

In this paper there is described an outlying series of Paleozoic rocks which occupy a narrow belt extending from the Archean highlands of New Jersey into Orange county, New York. The general geographic relations are shown in figure 1. The rocks are limestones, shales, conglomerates, quartzites and flagstones, ranging from Middle Cambrian to Middle Devonian in age. The harder members give rise to high rough ridges, of which the most prominent are Skunnemunk, Bearfort, Bellvale, Green Pond, Copperas, Kanouse and Bowling Green mountains. Greenwood lake lies in one of the principal valleys.

*Printed by permission of the Director of the United States Geological Survey.

The rocks are comprised in about nine formations, of which the distribution and structural relations are shown in plate 17. The uppermost member is a coarse conglomerate which constitutes the higher portions of Skunnemunk and Bellvale mountains in New York and of Bearfort mountain in New Jersey. Its age is Middle Devonian. It is underlain by a series of flaggy sandstone which merges into dark shales below. There is another prominent conglomerate in Green Pond, Bowling Green, Kanouse and Copperas mountains in New Jersey, and some smaller ridges in New York, which is somewhat similar in character to the upper conglomerate, but its age is Upper Silurian. There are also thin discontinuous sheets of conglomerate or conglomerate-quartzite of Oriskany age and a few small areas of conglomerate associated with the Cambrian limestone. This Cambrian limestone occurs at intervals along the margin of the belt, and is unconformably overlapped by the various other members. The Helderberg limestone areas are in greater part associated with the Oriskany beds, and they have been found at many localities.

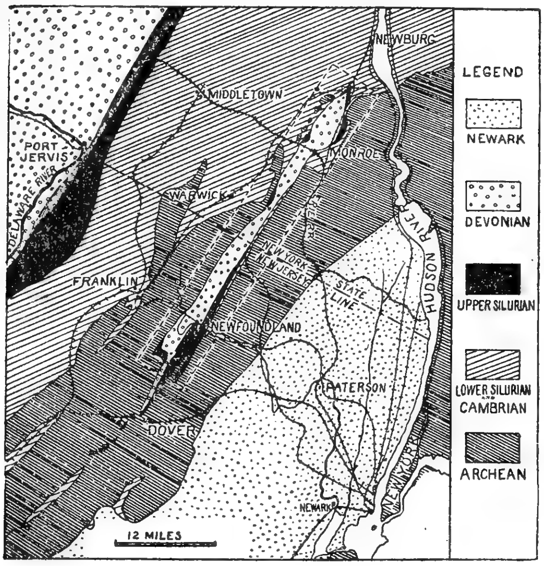


FIGURE 1.—*Geologic Map of northern New Jersey and adjacent Portions of New York.*

The area enclosed by the broken line is shown on plate 17.

## THE FORMATIONS.

*Review of their Investigation.*—The formations have been assigned to various horizons by previous observers and much uncertainty has always prevailed in regard to their ages. A list of the principal observers and their views is presented in the accompanying table, page 369.

E. Emmons* and T. Sterry Hunt† have expressed an opinion that the conglomerates and flags were representatives of the first graywacke of Eaton, but they do not appear to have made field studies of the region.

The principal contributions have been the reports by Horton and Mather; Cook, 1868; Smock, and Merrill, and the announcement by

* Geology of New York, Second District, Albany, 1842.

† The Taconic Question in Geology, part i: Trans. Roy. Soc. of Canada, vol. i, section iv, 1883, pp. 220, 253–254.

NEW YORK.

| | Horton [1] and Mather. 1839–1843. | Cook.[2] 1863-1868. | Martin.[3] 1871. | Cook [4] and Smock. 1874. | Smock.[5] 1884. | Darton. 1884–1885. | Darton. 1894. |
|---|---|---|---|---|---|---|---|
| Skunnemunk conglomerate | Oneida | Cambrian | | Cambrian. | Devonian | Devonian | Devonian. |
| Hamilton flags | Hudson | Cambrian | Devonian. | Cambrian | Devonian | Devonian | Devonian. |
| Monroe shales | Hudson | Hudson | | Hudson | Devonian (?) | Devonian | Devonian. |
| Oriskany | Oneida | Oneida and Cambrian | | Oneida and Cambrian. | Oneida and Cambrian. | Oriskany | Oriskany. |
| Helderberg limestone | Helderberg (in part) | | | | | Helderberg | Helderberg. |
| Green Pond conglomerate | Oneida | Cambrian and Oneida | | Hudson | | Oneida | Oneida. |
| Hudson shales | Hudson | Hudson | | Hudson | Hudson | Hudson | Hudson. |
| Limestone | Lower Silurian | Lower Silurian | | Lower Silurian | Lower Silurian | Lower Silurian | Cambrian. |

NEW JERSEY.

| | Rogers.[11] 1836–1840. | Cook.[6] 1863–1868. 1874–1882. | Smock.[5] 1884. | Cook.[7] 1886. | Darton. 1884–1885. | Merrill [8] 1887. | Cook.[9] 1889. | Darton. 1894. |
|---|---|---|---|---|---|---|---|---|
| Skunnemunk conglomerate. | | Cambrian | Devonian | Oneida | | Oneida | Cambrian | Devonian. |
| Bellvale flags | | Cambrian | Devonian | Hudson | | Devonian | Cambrian | Devonian. |
| Monroe shales | | Hudson | (?) | Hudson | | Devonian | Hudson | Devonian. |
| Oriskany | | Cambrian and Oneida | Oneida | | | Oriskany | Cambrian | Oriskany. |
| Helderberg limestone | | Trenton | Trenton | | Helderberg | Helderberg | | Helderberg. |
| Green Pond conglomerate. | Trias | Cambrian | Devonian | | Oneida | Oneida | Cambrian | Oneida. |
| Hudson shales | | | | | | | | Hudson. |
| Limestone and conglomerates. | | Lower Silurian | Lower Silurian | | | | | Cambrian[10] |

1. Report on the Geology of Orange County, by William Horton, pp. 146–149, 151–153, 165. In Third Report of Mather on the First District of New York. Albany, 1839. Geology of New York, First District, by W. W. Mather, Albany, 1843, pp. 362–365.
2. Report of Geol. Survey of New Jersey, for 1863, Trenton, 1864, p. 9; Report of State Geologist of New Jersey, for 1864, Trenton, 1865, map; and Geology of New Jersey, Newark, 1868, pp. 79–89 and map.
3. Proc. N. Y. Lyceum Nat. Hist., vol. i, pp. 259–260.
4. [Map of] Northern New Jersey, by G. H. Cook and J. C. Smock.
5. Report of State Geologist of New Jersey, for 1884, Trenton, 1884, pp. 29–56.
6. Report of Geol. Survey of N. J., for 1863, Trenton, 1864, p. 9; Report of State Geologist of N. J., for 1864, Trenton, 1865, map; Geology of New Jersey, Newark, 1868, pp. 79–89, maps; [Map of] Northern New Jersey, 1874, and Geol. Map of New Jersey, scale 6 miles to 1 inch, with Ann. Rep. of State Geologist of New Jersey, for 1882.
7. Report of State Geologist of New Jérsey, for 1885, Trenton, 1886, plate opposite page 109.
8. In Report of State Geologist of New Jersey, for 1886, Trenton, 1887, pp. 112–122.
9. Atlas of New Jersey, geological map of the state, on a scale of 5 miles to 1 inch.
10. According to a recent determination by C. D. Walcott.
11. Report on Geol. Survey of N. J., by H. D. Rogers, Philadelphia, 1836; Description of Geology of N. J., by H. D. Rogers Philadelphia, 1840.

Martin in 1871 of the discovery of Devonian plant remains in the flags of Skunnemunk mountain.

The classification by Horton and Mather of all the conglomerate beds in Orange county with the Shawangunk grit was based largely on the association with Helderberg limestone and red shales near Cornwall Station.

In the "Geology of New Jersey," 1868, Cook described the New Jersey portion of the region in considerable detail, and in the accompanying colored map of the Azoic and Paleozoic formations, represented the extension of the rocks in Orange county. The principal occurrences of fossiliferous limestones in the Green Pond region were announced in this report, but unfortunately they were mistaken for the Trenton formation. As the conglomerate of that region was clearly seen to underlie these limestones, it was classed as Potsdam, together with its supposed extension northward and the associated flags. This opinion prevailed for many years, and no new light was thrown on the subject until the discovery by Martin of Devonian plant remains in the flags on the southeast slope of Skunnemunk mountain. This discovery did not appear to attract much attention until in 1884, when Smock reëxamined portions of the region and prepared a report for the Annual Report of the State Geologist of New Jersey for that year. Smock found additional plant remains in the flags, and pointed out that as the conglomerate which caps Skunnemunk mountain lies on these flags, its age was approximately Middle Devonian. Apparently the conglomerates in the Green Pond region in New Jersey were supposed to belong to the same horizon, but lying directly on the Archean to the eastward and on "Trenton" limestone to the westward.

I began my studies of the belt by a short visit in the autumn of 1884, and I have revisited it many times since for short trips. In the summer of 1885 I found that the fossiliferous limestones in the Green Pond region were Helderberg in age, and this fact was communicated to the late Dr. G. H. Cook, then state geologist of New Jersey. At the same time it was ascertained that the Green Pond conglomerate was underlain by the older limestones east of Newfoundland, and from these two facts it was inferred that it was approximately Oneida in age. The discovery of Upper Silurian fossils in the overlying limestones was also announced to Dr. T. Sterry Hunt early in 1886, and by him published in his Mineral Physiology and Physiography, 1886, page 591.

In 1886 Dr. Cook sent Messrs Britton and Merrill to examine the Helderberg limestones in the Green Pond region, and further supplies of fossils were obtained, together with Oriskany fossils from an associated quartzite. Dr. Merrill remained in the region for some time and worked

out some local features of structure and stratigraphy which showed very clearly that the Green Pond conglomerate was approximately Oneida in age, and that the shales west of Green Pond mountain were Lower Devonian. He states near the conclusion of his report that this "Oneida" conglomerate extends northward along the western ridge of Bearfort mountain, but no extended examination was made of the region. Cook gave a section in his report as state geologist for 1885,* in which a central ridge of the mountain is shown as "Oneida conglomerate" (?) flanked by "Hudson river slate." This, as will be shown later, is an error, for the conglomerates are the Skunnemunk beds and the associated flags and shales are of Hamilton age.

In the New Jersey map for 1889 Cook colored the conglomerates of Bearfort, Green Pond, Kanouse, Bowling Green and Copperas mountain as "Potsdam," and the slates in the adjoining slopes and valleys as "Hudson river."

In 1892 Mr C. S. Prosser † gave a résumé of previous writings on the belt, and discussed at length the age of the plant beds in Skunnemunk mountain which are considered Middle Devonian in horizon.

In 1893 Mr A. F. Foerste ‡ made a short visit to the region about Newfoundland, and states his opinion that the conglomerate is Oneida, and the red quartzite Medina in age.

*Skunnemunk Conglomerate.*—In its typical development this formation is an aggregation of quartz and quartzite pebbles and bowlders in a red or reddish quartzitic matrix. It is very hard in texture and massively bedded. The pebbles and bowlders in greater part average from one to two inches in diameter. Some are five and six inches in diameter; many are from three to four inches, and they are mostly well rounded, but a moderate proportion of them are subangular. They are closely packed in the matrix. White, glassy quartz predominates somewhat, and the contrast of this material with the red color of the matrix gives a characteristic aspect to the rock. The quartzite pebbles are mostly dark red brown in color and they sometimes include pebbles of quartz. More or less finer fragmental products, consisting mainly of white quartz, red quartzite and red argillaceous materials, are included in the matrix.

In Skunnemunk mountain the conglomerate constitutes the two high crests which extend along the center of the range, and for some distance it also floors the deep intervening valley. The general relation of these features is shown in sections I and II of plate 17.

The mountain is everywhere rugged, but the conglomerate area is ex-

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* Trenton, 1885, plate opposite page 109.

† Notes on the Geology of Skunnemunk Mountain, Orange County, New York: Trans. New York Acad. Sciences, vol. 11, pp. 132–151.

‡ Am. Jour. Sci., 3d ser., vol. xlvi, pp. 440–441.

ceptionally so, as the formation gives rise to high cliffs and bare, rocky slopes. The thickness of the conglomerate in this region has been estimated at 300 feet by Smock, and this estimate appears to be a reasonable one. In the basal beds the pebbles rapidly decrease in size and number and the matrix becomes a gray sandy quartzite which constitutes a series of beds of passage into the great mass of underlying flags. Owing to its prominence in this mountain and the suitability of the name, it is proposed to designate the formation the Skunnemunk conglomerate.

In Bellvale and Bearfort mountains the Skunnemunk conglomerate attains considerably greater development than it has northward, for it has a thickness of 2,500 feet in the widest and deepest part of the synclinal. As the axis of this flexure rises to the south and to the north, the amount of conglomerate infolded, gradually decreases and its area finally terminates.

The character of the formation in Bearfort and Bellvale mountains is very similar to that which it has in Skunnemunk mountain. In its lower members, however, it includes for some distance a basal series of red slates, which are usually overlain by a greater or less amount of red quartzitic sandstones. There are also local series of red slates and streaks of less conglomeratic material higher up in the formation. The harder beds are traversed by many small veins of quartz, which add considerably to the bright variegation in the colors of the rock.

As the lowest beds of the formation come into the flexure in Bellvale mountain, they are seen to consist of light-colored sandy quartzites containing few pebbles, but much checkered by small quartz veins. On the road across the mountain from the northern end of Greenwood lake the flags merge upward into reddish quartzite containing several red slate streaks, which gives place rapidly to a thick mass of coarse typical conglomerate which constitutes the crest of the mountain. On the western slope the reddish quartzite comes up on the other side of the synclinal and is underlain by three to five feet of bright brown-red slates which lie against the gneiss.

South from the road the mountain widens rapidly and opposite the southern end of Greenwood lake it has three crests, of which the conglomerate constitutes the two western ones. The region is very high and steep, but it is crossed by two gaps near the lines of sections VII and VIII, plate 17, in which there are many exposures. In the northern gap the lower members on the eastern limb of the synclinal are red quartzitic sandstones which merge into a great mass of underlying flags through a series of slabby sandstones, quartzitic and reddish above and softer, thinner bedded and light gray in color below. In the axis of the flexure and westward there is a great thickness of red conglomerate.

There is a longitudinal valley along the boundary of the crystalline rocks at the western mouth of the gap, which is apparently underlain by red slates, for this member outcrops along the slopes southward. Here also for some distance the shales are underlain by a few feet of flags.

In the southern gap, which crosses Bearfort mountain about four miles south of the southern end of Greenwood lake, the exposures are somewhat interrupted by swamp-filled depressions and by drift. Beginning on the east side, there is a basal series of red quartzitic sandstones and slates which lie along the eastern side of the middle ridge. They give place above to a thin, local series of gray flaggy beds which are overlain by the great mass of typical conglomerate. There is a local bed of red shales in this conglomerate not far from the axis of the synclinal. The basal red slates with red pebbly quartzites which underlie the conglomerate are exposed at the west end of the gap and they are underlain by small amounts of gray flags. Along the road, a mile south of this locality there is an exposure of the conglomerates very near the gneiss.

In the region northwest of Newfoundland the Bearfort mountain rapidly decreases in height, the synclinal opens and rises, and the conglomerate has been eroded away. The red and gray quartzite beds and the red slates cross the end of the mountain around the rim of the synclinal. The red slates are well exposed on the south shore of the new reservoir at Clinton falls, two miles northeast of Newfoundland, overlying the flag series and the synclinal is clearly exhibited by them.

The age of the Skunnemunk conglomerate is not definitely known. It is suggested that it may represent the Oneonta horizon, for the deposition of the Oneonta formation in central New York was characterized by an abrupt change to coarse sedimentation. Possibly the age is later than this, and the formation may be equivalent to the coarse beds of Chemung age in the southern Catskills, or it may be a purely local feature.

*Bellvale Flags.*—The hard, thin-bedded sandstones, which contain Devonian plants on Skunnemunk mountain, extend southward through Bellvale mountain and along the eastern side of Bearfort mountain nearly to Newfoundland. They merge into dark-colored slates below, but the horizon of transition is a somewhat variable one. The greatest development of the formation is along the eastern side of Bearfort mountain, where the thickness is not less than 2,000 feet. In the eastern part of Skunnemunk mountain the amount has been estimated by Smock at 1,300 feet, including the underlying slates, but it is somewhat greater than this to the northward. The flags terminate northward in the northern slope of Skunnemunk mountain southwest of Cornwall Station. The rocks present some variation in color, hardness and thickness of bedding, but the predominating character is a dark gray, hard, moder-

ately fine-grained, slabby sandstone. It has been quarried to some extent northwest of Monroe for use in flagging, but the quality of the flags is not very satisfactory. Among the upper members there are scattered conglomerate streaks, of which the most prominent is a twelve-foot bed in a prominent spur on the eastern side of the mountain near the line of section III, plate 17. The upper beds are massive and more or less quartzitic, and it is these which merge into the Skunnemunk conglomerate. At Clinton falls, west of Newfoundland, these massive upper beds are finely exposed, underlying the red slates. They are there and at many other points much broken and gashed with veins of quartz. As Bellvale mountain consists largely of these flags, it is proposed to designate them the Bellvale flags.

The occurrence of the plant remains has been referred to a number of times in preceding pages, for they have afforded most important evidence as to the age of the formation.

They comprise the following species: *Lepidodendron gaspianum*, Dawson; *Psilophyton princeps*, Dawson; *Calamites transitionis*, Goeppert, and some others less definitely identified.

Professor D. S. Martin was the original discoverer of these remains, which he found in an opening for coal on the southwest slope of Skunnemunk mountain at a point about a mile and a half due north of Monroe station. Smock found additional remains in the old flag quarries near by, where plant fragments are abundant. I have also found fragments at Woodbury falls, on the opposite side of the mountain, and at Clinton falls, west of Newfoundland.

Prosser* has recently reviewed the occurrences of these remains, obtained new supplies, and discussed their age. The conclusion at which he has arrived is that the plants represent a Middle Devonian horizon, but that precise correlation is not practicable.

*Monroe Shales.*—The shale series underlying the Bellvale flags extends around the lower slopes of Skunnemunk mountain, down the valley east of Bellvale and Bearfort mountains, and over a wide area in the low region north of Bowling Green mountain. They are known to occupy the valley southeast of Milton for a number of miles, but their southern termination is not yet definitely ascertained. Their greatest thickness is in the valley and slopes south of Greenwood lake, where it amounts to about 900 feet. On the southeast side of Skunnemunk mountain their thickness is greatly reduced, apparently by gradation into more arenaceous beds. At Monroe and about the northern end of the mountain they have a thickness of about 200 feet. The most extensive exposures

*Notes on the Geology of Skunnemunk Mountain, Orange County, New York. N. Y. Acad. Science, Trans., vol. 11, pp. 132–151.

are in the valley south of Greenwood lake and in Pea hill, near Cornwall Station. They outcrop in characteristic development at a number of points about Monroe, and this name is suggested as an appropriate designation for them.

The rocks are dark gray to black, fissile to slaty shales, and they are nearly everywhere fossiliferous. The fossils are usually not numerous nor conspicuous, but they may readily be found by careful searching. These slates were considered "Hudson River" in age for many years, and they are not unlike the Hudson slates in general appearance. In 1886 Britton and Merrill ascertained definitely that the shales in the area west of Green Pond mountain were Lower Devonian, as they overlaid the Oriskany grit. Only one fossil was found by these observers, a *Palæoneilo*, of Upper Devonian horizon, according to Professor James Hall, but it added much weight to the structural evidence. During the past few years I have obtained fossils from many localities along the Greenwood lake valley and all around the lower slopes of Skunnemunk mountain. Professor James Hall kindly examined them for me and he finds that they are typical lower Hamilton (group) species. The most prolific localities I found were along the shore of Greenwood lake, along the roadside two miles due west of Monroe, and at Pea hill, a mile southwest of Cornwall Station.

*Oriskany Quartzites.*—In 1886 Britton and Merrill discovered fossiliferous Oriskany beds at Newfoundland and at several points to the southwest. I find that the formation also occurs at intervals northward along both sides of the Devonian belt, but it is much less fossiliferous.

The best exposure about Newfoundland is that described by Merrill which is just south of the turnpike on the southern and eastern slopes of the first ridge west of Kanouse mountain. This is about 750 yards east-northeast of the depot. The ridge is heavily drift-covered and there are only a few small outcrops, but they are quite abundantly fossiliferous. *Spirifer arrectus* is the most conspicuous fossil, but, as noted by Merrill, there are many casts of other brachiopoda, apparently including *Rensselæria*, and cyathopylloid corals. The rock is in greater part a light-colored quartzite containing quartz grains and pebbles. Some portions are calcareous and weather to a loose grit, and it is mainly in these that the fossils are exhibited.

Merrill mentions another locality of the rock south of Newfoundland depot, but here the fossils are not so well preserved. Along the western slope of the Green Pond mountain and the northern and eastern foot of Bowling Green mountain there are occasional exposures of the grit, and there is a small mass of it on the east side of Green Pond mountain at Middle Forge. The thickness in the Newfoundland region and south-

ward is estimated by Merrill to be 50 feet, but owing to lack of continuous outcrop across the formation I could not verify this.

North from Newfoundland no clear exposures were found, and the formation appears to finally thin out under the drift on the western slope of Kanouse mountain. It comes out again along the west shore of the southern end of Greenwood lake, where it attains considerable prominence in an anticlinal ridge, as shown in section VII, plate 17. In the southern end of the ridge there is a synclinal of Monroe shales, and the Oriskany appears along its base, but farther north for some distance it constitutes the crest of the ridge along the lake shore and comes up again in a long, rocky island in the lake. North of this island it constitutes a small point three-quarters of a mile south of the state line, where it is overthrust on the Monroe shales. The rock in this region is a white, light gray or buff quartzite, containing much coarse sand and more or less quartz pebbles. A few indistinct casts of fossils were observed near the southern end of the area, but they do not appear to be determinable. As the overlying shales contain abundant lower Hamilton fossils and Helderberg fossils were discovered in a thin streak of underlying limestone, I have no doubt as to the approximate Oriskany age of the quartzite. The thickness here is about 28 feet. This area, together with the adjoining belt of Green Pond conglomerate and quartzite, were shown by Cook on the map in the Geology of New Jersey, 1868, and mentioned in the text as Oneida.

In a knoll just north of the northern end of Greenwood lake there is a small exposure of quartzite, with coarse sand grains and occasional pebbles, which I believe to be Oriskany. It dips conformably under the Monroe black shales, but is not exposed in contact with them. It is shown in section VI, plate 17. The valley north of this knoll is heavily drift-covered and the extent of the quartzite could not be ascertained.

On the west side of Bellvale and Skunnemunk mountains there are a number of exposures of the quartzite, some of which have considerable prominence. The first one from the south is shown on section V, plate 17. It is a mass about 200 feet in length, lying on the east slope of a ridge of Hudson shale. It is abruptly terminated by a cliff southward and appears to thin out to the northward. It dips gently to the east and passes conformably under fossiliferous Monroe shales. It is a hard, white quartzite, containing an occasional white quartz pebble and more or less coarse quartz sand. Thirty feet are exposed. No fossils were found. Half a mile north there is another mass of the rock, similarly related in structure to Hudson shales on the west, and Monroe shales to the east. It extends for about a mile, and the glistening white rocks in its steep eastern front render it a conspicuous feature. It contains local

conglomerate beds of white quartz pebbles and a few reddish streaks. Ninety to one hundred feet are exposed.

These two areas are shown as Oneida on the map of the Paleozoic and Azoic formations accompanying the Geology of New Jersey, 1868, but I believe that they are Oriskany. They are very similar to the other Oriskany beds, and have the same relations to the Monroe shales. Their proximity to the Hudson formation is due either to overthrust or overlap. Unconformity to the Hudson beds is exposed at a number of points, particularly at the southern end of the southern mass, and it appears to be due to overlap. Along the strike, a mile northeast of the southern end of the larger mass of quartzite above described, there are three small lens-like masses of the quartzite, and in 1885 I discovered under the southernmost of them a limestone containing unmistakable Helderberg fossils. This strengthens very greatly the view that they are all of Oriskany age. The relations of this limestone are shown in section IV, plate 17. There is no possibility of overthrust at the base of the quartzite at this point, and the conformity of the overlying Monroe shales is clearly apparent.

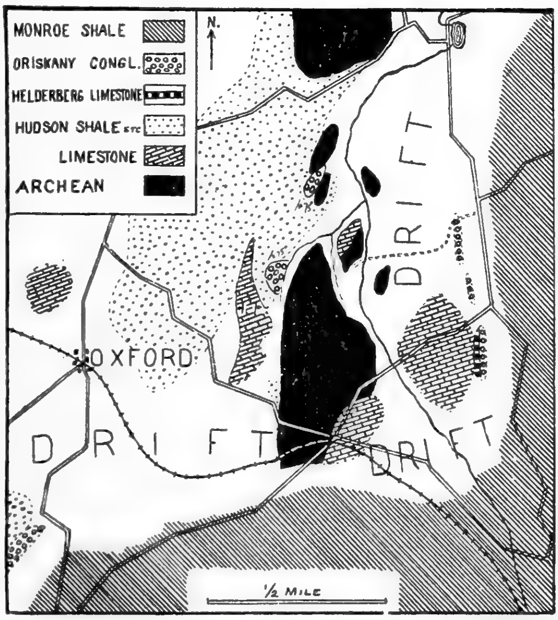


FIGURE 2.—*Region northwest of Monroe, New York.*

The three small areas constitute a line of knolls along the foot of the western slope of Skunnemunk mountain, and are probably part of a continuous layer, which is cut off northward by overlap or possibly by a fault. They are white quartzites, with few pebbles, and present a thickness of about 25 feet at greatest. Along the Hudson shale and sandstone and crystalline slopes westward there are two small outliers of similar quartzite, but more conglomeratic in character, which appear to be deposited across the unconformable overlap of Hudson beds, on the gneiss. Smock has a map of this region in his paper, in which one of the areas is shown as Potsdam and the two overlapping masses as Oneida. No fossils were found, but from the evidence above presented I believe the masses are all Oriskany. The areal relations in this district are shown in figure 2.

In this map the three lenses of quartzite are shown on the right-hand side, and the two areas of conglomerate are near the center. The latter

appear to be remnants of shore deposits lying against the gneiss and some gritty sandstones of Hudson age. To the north there is a general overlap westward of the Monroe shales and Bellvale flags. In the extreme southwest corner of the map is the end of the quartzite due west of Monroe.

Continuing northward along the same valley there is, between Woodcock hill and Skunnemunk mountain, a ridge of considerable prominence in which the quartzites are again exposed. The rock is a white conglomeratic quartzite, and a thickness of about 80 feet is seen. No fossils were observed. It dips eastward with perfect conformity under Monroe shales, in which many lower Hamilton fossils were found. It is cut off on the westward by a clearly exposed overthrust along which it abuts against the Cambrian limestone and for a short distance, against some shales of probable Hudson age. Its relations are shown in section II, plate 17, and in figure 6, page 390. It is represented as Oneida on the map accompanying the "Geology of New Jersey," 1868, and by Smock in the section in his paper.

Two miles north of the end of this ridge, at the northern end of Skunnemunk mountain, I find there is another mass of the quartzite brought up by the pitch of the synclinal. It is underlain by the Helderberg limestones at the Cornwall Station locality, and to the southward is clearly overlain by fossiliferous Monroe shales. It is in the northern end of Pea hill, a northern foothill of Skunnemunk mountain, and is conspicuously exposed along and near the road from Woodcock hill to Cornwall Station. It is a conglomeratic quartzite similar to the others southward, but consists mainly of somewhat smaller pebbles and large sand grains. No fossils were found, but careful search was not made. About 30 feet are exposed, and the area of outcrop is only a couple of acres. Its relations are shown in section I, plate 17 and in figure 3. Possibly other exposures of the Oriskany may be found along the edges of the Monroe shales, for I did not examine its entire length. There are long distances in which there is drift cover, but in several localities the formation is apparently entirely absent.

In designating the formation Oriskany I do not intend to give the impression that it is precisely equivalent to the Oriskany sandstone of central New York. Probably the sediments comprise the greater part of Oriskany group if the sedimentation was continuous in this belt.

*Helderberg Limestone.*—The limestones of this formation occur at intervals along the belt to which this paper relates, and their characteristic fauna affords important evidence as to the stratigraphic position of the associated formations. The most interesting locality is at Cornwall Station, where the occurrence of the formation was announced over half

a century ago by Horton and Mather. The discovery of the southern extension of the formation was made early in 1885, when I found that the so-called Trenton limestones south of Newfoundland and at Longwood and Woodstock were of Upper Silurian age. Slightly later the fossils were discovered at Greenwood lake, and last autumn I found them in Pine hill, northeast of Monroe.

I described* the Cornwall area in considerable detail in 1886, but a résumé of its principal features may be of interest here.

In figure 3 are shown the relations in this region. The beds have an aggregate thickness of about 40 feet and comprise the lower Shaly limestone, Pentamerus limestone, and water-lime members. They present their usual characteristics and faunas, especially the Shaly member, which is very fossiliferous, but are considerably attenuated in thickness. They are exposed for a length of about a mile. The lower members thin out or are faulted down, in the southern part of the area, in which the Shaly limestone lies directly on Longwood red shales. Along the contact of this limestone and the shales there are local developments of limonite which were worked to a small extent some years ago. The Shaly limestone is well exposed in the old ore pits and contains a varied and abundant fauna, which was described in detail in the paper mentioned above. The principal exposures in the northern part of the area are in the cut of the New York, Ontario and Western railroad. Here there are seen fifteen feet of massive, dark drab colored, impure limestone containing *Pentamerus galeatus*, *Atrypa reticularis* and some other forms, underlain by 30 feet of thinner bedded, impure, dark-colored limestone, containing *Leperditia alta* in their upper beds.

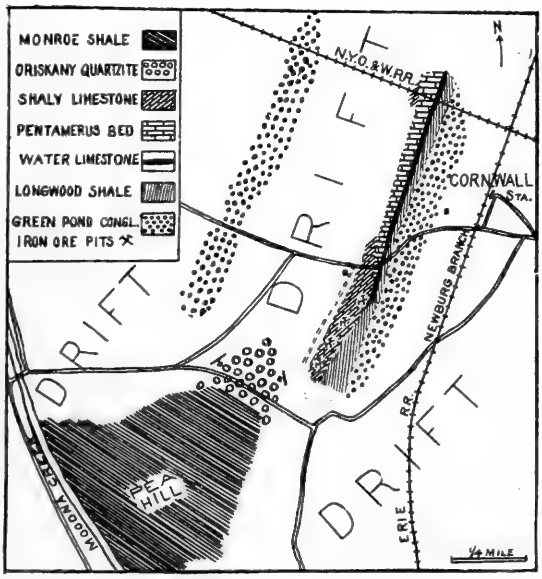


FIGURE 3.—*Region west and south of Cornwall Station, New York.*

The Helderberg formation probably extends around the Oriskany area to the westward, but there are low grounds and drift in that direction and no outcrops were found. To the southward for several miles there

* On an Area of Upper Silurian Rocks near Cornwall Station, eastern central Orange County, New York: Am. Jour. Sci., 3d ser., vol. xxxi, pp. 209-216.

are showings of iron ore at several points, but I saw no exposures of the associated rocks.

On the western slope of Pine hill, which lies half way between Cornwall Station and Monroe, I have recently discovered several small outcrops of the formation. This locality is about half a mile northeast of Highland Mills station of the Newburg branch of the Erie railroad. The beds lie on a great mass of Longwood red shales and, as at Cornwall Station, there are streaks of limonite along the contact. The rock is a deeply decomposed sandy limestone of light buff color, and it contains a fairly abundant fauna. *Orthis oblata*, *Strophomena rhomboidalis*, *Spirifer macropleurus* were the most clearly marked species noticed, but fragments of several other forms were observed. The thickness is about 30 feet, but there is no complete section exposed. The overlying formation is Monroe shale containing occasional fossils. The relations at this locality are shown on the right-hand end of section III, plate 17.

There is a small showing of purplish buff shale half a mile south of Highland Mills station on the road to Central Valley, which appears to be an extension of this area, but no fossils were found. In the surrounding region and to the southward there is a heavy drift cover. On the opposite side of Skunnemunk mountain there occur the Helderberg limestones mentioned on page 377 and shown in figure 2. The outcrop is under the western face of the southernmost area of Oriskany quartzite, and the thickness of the bed is not over a yard or two. The rock is a thin bedded, dark blue gray, moderately pure limestone and the fossils are rare and poorly preserved. They were examined by Professors Hall and Whitfield, and it was found that they were undoubtedly Upper Silurian in age. A ventral valve of *Spirifer cyclopterus* and some crinoid stems were the best preserved remains, but *S. macropleurus* and *Orthis oblata* were less clearly exhibited. The beds lie on the light blue gray, glimmering limestone of supposed Cambrian age, but the contact was not observed.

Careful search was made for the extension of this Helderberg limestone under the other quartzite areas northward, but owing to drift and débris no exposures were found.

The next exposure southward was discovered in 1889, on the western slope of Bellvale mountain, at a point half a mile north of the road from Greenwood lake. The outcrop is a very small one, and is in an old field near the bottom of the slope. The rock is a dark gray, moderately pure limestone. Only one fossil was found, and that was a fragment of a badly crushed shell, but it had a punctate surface, which strongly suggested *Strophonella punctulifera*, Conrad. It was clearly not a fragment of coral, the surface of a tribolite, nor a cast of *Bucania punctiferons*. The

underlying rock was the light gray, arenaceous limestone of supposed Cambrian age which here constitutes a small outlier resting on the crystalline rocks.

Adjacent to the southern part of the Oriskany quartzite area, near the southern end of Greenwood lake, there is a small showing of limonite, into which a pit was sunk some years ago. This pit has caved in and was nearly obliterated at the time of my visit, but on some of the material which had been thrown out in its excavation I found a few small fragments of fossils. One of the remains was clearly *Orthis oblata* and a portion of *Strophomena rhomboidalis*, or possibly *Strophodonta beckii*, was also recognized. The bed from which they came directly underlies the Oriskany quartzite, and is, as usual, underlain by red shales, so that there is here the normal sequence. To the south there are low grounds and drift, and to the north the strike carries the formation out under the lake.

The Helderberg formation in the Newfoundland region and to the southward appears to extend continuously for a long distance. The principal exposures are in the synclinal valley between the northern end of Green pond and Copperas mountains and along the western slope of Green Pond mountain. The exposures in the synclinal begin a mile and a quarter south of Newfoundland depot and extend for some distance southward up the valley and the slopes southeast. The rock is a dark gray, impure limestone, with a tendency to slaty cleavage, and very like the Shaly limestone series in Ulster and Greene counties. Abundant *Chætetes lycoperdon* of the ramose variety, various bryozoöns, *Atrypa reticularis* and a *Rhynchonella* resembling *R. neglecta* of the Niagara were the best defined remains which I found in 1885, but *Spirifer Vanuxemi* and *Meristella* sp., were found by Britton, according to Merrill.

There are a number of exposures of similar limestone along the western slope of Green pond mountain, but the most extensive and best known are in old quarries southeast of Milton, at Woodstock and Upper Longwood. The fossils I obtained here and those mentioned above were kindly examined for me by Professor Whitfield. At Upper Longwood the most abundant remains are *Chætetes lycoperdon*, mainly of ramose form, and with them there was found a well preserved *Mitchellena*. There were an Orthis resembling *O. elegantula*, *Atrypa reticularis*, *Stroponella Headleyana*, a strophomena resembling *S. subplana* of the Niagara, *Streptorhynchus woolworthana*, fragments of Spirifer probably *S. perlamellosus* and two rhynchonellæ, one like *R. neglecta* of the Niagara and the other apparently a young individual of *R. nobilis*.

These limestones lie directly on the Longwood red shales and are overlain by the Oriskany grit, all in conformable sequence. How far

the formation extends southward along the flank of the Green Pond mountain is not known. It is probable that it extends around the end of the Bowling Green mountain, but owing to drift cover there is but little evidence on this point. South of Milton there are several small showings of limestone near the red shales at the foot of Bowling Green mountain, and although they may not all be in place they do not appear to be drift bowlders. Fragments of *Chætetes* were the only fossils found in them, but I have no doubt as to their Helderberg age.

*Longwood red Shales.*—These shales underlie the Helderberg limestone at Cornwall Station and Pine hill, and throughout their extent in New Jersey. They are also everywhere intimately associated with, and grade into the Green Pond conglomerate. There are similar shales having the same relations in Ulster county, New York, where they have been considered equivalent to the Clinton formation. As the most extensive exposures are along the Longwood valley east of Milton, it is suggested that they be designated the Longwood shales.

In the vicinity of Cornwall Station they extend along the western slope of the ridge and are exposed in the iron-ore pits and the cut of the New York, Ontario and Western railroad. In this cut, which is their northernmost exposure, the upper members are light-colored, thin-bedded quartzites, which have a thickness of 12 feet, and closely resemble the quartzites similarly lying between the water-lime and red shales in the Rosendale cement region of Ulster county. The quartzites are underlain by red beds, with green to buff layers, which break into shale on exposure.

In Pine hill there is a great development of the shales, and they have been quarried to some extent near Highland Mills station for road metal. They are bright red in color, and have a thickness of about 70 feet. They are overlain by ferruginous beds at the base of the Helderberg limestone, and lie on red quartzites of Green Pond age. They extend for about two miles in a north-and-south direction, and then terminate either by faulting or thinning out.

They are next seen near the south end of Greenwood lake in a small belt extending for half a mile between Green Pond quartzite and the Oriskany ridge. They are immediately overlain by the ferruginous limestone containing Helderberg fossils described on page 381.

The red shales appear at intervals along the western slope of Kanouse mountain, but they are in greater part overlain by drift. In the region south of Newfoundland they are exposed at a few localities, notably along the road at two points about three-quarters of a mile south of the depot. This locality is carefully described by Merrill, who has figured the slaty cleavage which it exhibits. This cleavage is at an oblique angle to the bedding, and is usually conspicuous in the areas in New Jersey. The

formation extends along the western slope of Green Pond mountain, and around the northern end of Bowling Green mountain, where it is frequently exposed. The thickness in New Jersey is estimated at 200 feet by Merrill, but its average amount does not appear to be more than 150 feet.

The Longwood red shales are similar in general appearance to some of the shales associated with the Skunnemunk conglomerate in Bearfort mountain, but, as noted by Merrill, the stratigraphic relations are entirely different. Where they are associated with quartzites in New Jersey they are *underlain* by them.

*Green Pond Conglomerate.*—The greatest development of this formation is in New Jersey, where it is continuous over a wide area, and gives rise to a number of prominent ridges. In New York there are three small outlying areas: Pine hill, northeast of Monroe, and two small ridges west of Cornwall station. Throughout its course it consists of coarse, red conglomerates below and buff and reddish quartzites above, and the characteristics of these members are uniform throughout. The conglomerates consist of quartz pebbles from one-half inch to two inches in diameter in greater part, in a hard, sandy, quartzitic matrix of dull red color. The proportion of pebbles to matrix is usually large, but there is local variation in this regard. The pebbles are mainly well rounded, but some subangular ones occur. They are almost all of quartz, and white or pinkish in color. No quartzite pebbles were observed. In this characteristic the Green Pond conglomerate differs greatly from the Skunnemunk conglomerate, but otherwise they are very similar. The thickness of the Green Pond conglomerate varies. In New York there are not over 60 feet, but in New Jersey it will probably be found to average about 150 feet in its greatest development in Green Pond and Copperas mountains. Owing to its extreme hardness and massiveness, it gives rise to high, rocky ridges with precipitous slopes in greater part. Green Pond, Copperas, Kanouse and Bowling Green mountains are the most prominent of these, and they occupy an area of considerable size in New Jersey. South of the south end of Green Pond mountain west of Dover there are outliers of conglomerates and sandstones probably of this age, of which the distribution is indistinctly shown in figure 1. They are described by Cook in the "Geology of New Jersey," 1868.

In the vicinity of Cornwall Station the conglomerate lies on Hudson shales; in Pine hill, on Cambrian limestone, at least in part; in Kanouse mountain, on slates possibly of Hudson age, northward, and on Cambrian limestone southward; in Green Pond, Copperas and Bowling Green mountains it lies directly on the crystalline rocks. The contact with the crystalline rocks is exposed along the upper part of the eastern slopes of

Copperas mountain, and the surface is a relatively level one. Small enclosed areas of the crystallines are bared by erosion of the conglomerate along the two anticlinals south of Newfoundland, and I find that gneiss extends to within half a mile of the depot in the western flexure. Along the axis of the eastern flexure, gneiss extends to and under Green pond and down the gorge of the outlet of the pond to the end of Copperas mountain. Along these anticlinals no actual contacts were found, but from many exposures in its vicinity the relative evenness of the floor was clearly apparent. In the Bowling Green mountain the conglomerate is wrapped around the northern end of a ridge of gneiss, but its contact relations were not observed.

The conglomerate becomes finer grained in its upper part and rapidly merges into the quartzites. These are moderately thick-bedded, very hard, fine-grained members, which vary in thickness from 250 feet about Newfoundland to 5 or 6 feet near Cornwall station. They are usually reddish or buff in color, but brown and light gray tints are often seen. The crest and western slopes of Green Pond, Kanouse and Copperas mountains and the northern slope of Bowling Green mountain consist of this rock. It is again exposed on the western shore of the southern end of Greenwood lake, along the crest of Pine hill, northeast of Monroe, and just west of the crest of the ridge at Cornwall Station. At Newfoundland it is well exposed a few yards west of the station, dipping around the declining end of the anticlinal.

The quartzites grade upward into the Longwood red shales, and the intergrading is exposed at a number of points along the west slope of Green Pond mountain and in New York. On the northwestern slope of Pine hill, beds of passage are finely exposed, and the red shale and red quartzite are interlaminated for a thickness of several feet.

The age of the Green Pond conglomerate and quartzite is approximately the same as the Shawangunk grit and Oneida conglomerate, and probably they also represent all or a portion of the Medina. They are, at any rate, the representatives of the great arenaceous sedimentation at the beginning of the Upper Silurian. The evidence of their position is mainly their intimate relation to the Helderberg limestone throughout and the fact that they overlie the Hudson shales in New York and probably also in New Jersey. Throughout their course in New Jersey and New York the upper quartzites grade into the Longwood red shales, and these into the Helderberg limestone, constituting a series which overlaps the Archean, the Cambrian limestone and the Hudson shales. This stratigraphic relation, as well as precise lithologic similarity, served to correlate the Pine hill and Cornwall station areas with those of the Green pond region in New Jersey. The superposition on the Hudson shale is

unquestionable in the Cornwall region, where the Green Pond, Longwood, Helderberg and other series present the full sequence. In New Jersey there are shales underlying the conglomerate along the east side of Kanouse mountain near its northern end, but it is not as yet demonstrated that they are Hudson in age.

The estimate of the total thickness by Merrill of 600 feet in the Newfoundland region is considerably too great. I find that the 500-foot cliff south of the station, on which his estimate is based, contains nearly 100 feet of crystalline rocks at its base, but probably a considerable portion of the original thickness of sandstone was removed from its summit. The formation appears to attain its greatest thickness at this locality, for the average amount is considerably less elsewhere.

The name Green Pond Mountain conglomerate or series has been applied to the formation by Cook, Smock and others, and, although originally always used to include the Skunnemunk conglomerate, it is, I believe, an appropriate name, with proper restriction, for the Upper Silurian member. The "mountain" may be omitted to advantage, as Green Pond is a typical locality. It is not proposed at present to separate the quartzite under a distinctive name.

*Hudson Shales.*—The Hudson shales are overlapped by the several Upper Silurian and Lower Devonian members in Orange county, especially to the north and west.

The formation consists mainly of gray to brownish gray shales, with more or less slaty cleavage. There are some sandy beds, notably, in the vicinity of the lines of sections IV and V, plate 17, which have a position near or at the upper part of the formation. These sandy beds are light gray in color, semi-quartzitic in composition and give rise to rough, rocky ridges of some prominence. They were found to contain a few *Orthis testudinaria* near the line of section V. They have been included with the Oriskany quartzite as Oneida and Potsdam by Cook in his 1868 and 1874 maps.

In 1885* I had the good fortune to discover fossils in this formation which definitely proved the Hudson river age of the slates. Since then many new localities of fossils have been noticed. The principal fossils are *Leptenæ sericia*, *Orthis testudinaria* and *O. plicatella*, but there are several others of typical upper Ordovician age. The overlap of Hudson shales on the crystalline rocks is a noteworthy feature in this region, and the small outlying Archean areas rise in greater part as "islands" through the shales.

* Preliminary Notes of Fossils in the Hudson River Slates of the southern Part of Orange County, New York: Am. Jour. Sci., 3d ser., vol. xxx, pp. 452–453.

In New Jersey there is a thin mass of shales, above alluded to, which extends along the eastern side of the northern part of Kanouse mountain between the Green Pond conglomerate and the Cambrian limestone, but no fossils have been discovered in them and their age is not definitely established. As they resemble the Hudson shales in appearance and appear to overlie the limestone unconformably in the usual way, and there are no shales of Cambrian age in the region northward, it is probable that they are Hudson.

*Cambrian Limestone.*—The greater part of the Green pond-Skunnemunk basin is underlain by a series of limestones which are an extension of the "magnesian limestones" of northern New Jersey. They are unconformably overlain by the other formations.

Along the eastern side of the basin they outcrop for some distance north and south from Greenwood lake, occupy a wide area east and north of Monroe, and are exposed at intervals south and east of Cornwall Station. To the southwestward they are bared of Hudson shales along the western side of Bellvale mountain, opposite the southern end of Skunnemunk mountain and along the eastern side of Woodcock hill. They are light colored, massively bedded rocks closely resembling the Calciferous of the Mohawk valley. They present the same characters throughout the belt, and I have no doubt as to the essential identity of the beds in the several areas represented on plate 17. Their distribution was in greater part shown on the map accompanying the "Geology of New Jersey," 1868, but I have found several other exposures and areas.

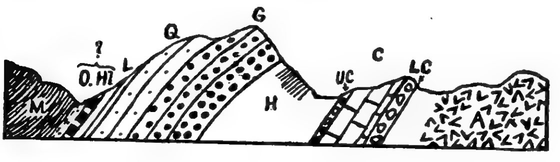


FIGURE 4.—*Cross section of the north rn End of Kanouse Mountain and the Valley eastward (looking north).*

*M* = Monroe shales; *O* = Oriskany grit; *Hl* = Helderberg limestone; *L* = Longwood shales; *Q* = Green Pond quartzite; *G* = Green Pond conglomerate; *H* = Hudson slates; *UC* = upper conglomerate; *C* = Cambrian limestone; *LC* = lower conglomerate; *A* = Archean.

These limestones were formerly supposed to be of Lower Silurian age, but in recent years fossils have been discovered in the region west of the Highlands by Beecher, Foerste, and others which indicate a Middle Cambrian age for some thickness of the lower members. Last autumn Mr C. D. Walcott* made the very important discovery of *Olenellus* in the area south of Greenwood lake, and thus definitely established the age of the beds, at least in this portion of the belt.

In the area south of Greenwood lake the limestone is underlain by a light colored quartzite, in part conglomeratic, which occurs at intervals

*A notice of this discovery will appear in the American Journal of Science for April, 1894.

for about three miles, and there is also a small mass of conglomerate overlying the limestone about three miles south of the lake. These beds have been referred to by several observers, and Smock * has given a section in which some of their relations are shown. Merrill † included the upper conglomerate in the Green Pond formation, and this was also suggested by Smock, but I found that there is an intervening mass of the supposed Hudson slate referred to on page 386. The relations are shown in figure 4, which is near the line of section VIII, plate 17, and through the beds in which Mr Walcott found the *Olenellus*.

Mr Foerste visited the locality in 1893, and he has stated the opinion ‡ that the limestone was the "magnesian limestone" of northwestern New Jersey and the underlying quartzite the "Olenellus" quartzite. He found no fossils.

## Structure.

*Flexures.*—The general structure of the region is synclinal, but there is considerable diversity in the shape of the main flexure and there are several subordinate flexures, notably in the Newfoundland region. The strike is northeast by north in Bellvale mountain and the region northward, but at Monroe there is an abrupt change in trend to northeast, which continues through Skunnemunk mountain and northward.

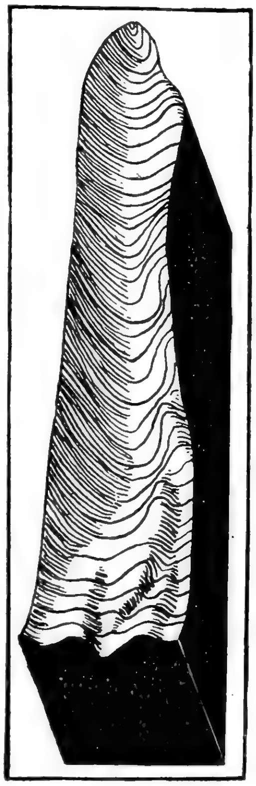

Figure 5.—*Flexures of the Green Pond-Skunnemunk Mountain Belt (looking northeast).*

In figure 5 I have attempted to show the nature of the flexures by a succession of sections drawn at the base of the Monroe shales.

The variations in steepness and pitch are, I think, the only noteworthy features of these flexures.

The close folding of the northern portion of the general syncline is exhibited in the northern end of Skunnemunk mountain and northward, and in Bellvale and Bearfort mountains. The open portion of the synclinal is in the central and southern portions of Skunnemunk mountain and the region from west of Newfoundland to Milton. The flags and shales in the southern end of Bellvale mountain exhibit a gentle synclinal, although there is much slaty cleavage and the dips are not al-

* Loc. cit., p. 52.
† Loc. cit., p. 115.
‡ Loc. cit., p. 441.

ways clear. The anticlinal which comes in from the south brings up the Oriskany, Helderberg and Longwood members at Milton, and the Green Pond conglomerate in the central part of Bowling Green mountain. The dips on the northern end of this mountain are semi-quaquaversal to the east, north and northeast, but southwest of Milton there is a synclinal with steep axial pitch to the north.

The principal anticlinal in New York is along the eastern side of Skunnemunk mountain, where the flags dip eastward down the slope of the mountain, but with a strong pitch to the north. This flexure apparently merges into a slight overturn of the eastern limb of the synclinal in the northeastern end of the mountain and about Cornwall Station.

The principal anticlinal southward is first apparent on the west side of the south end of Greenwood lake, where its relations are shown in section VII, plate 17. It brings up the Oriskany quartzite in a small, steep ridge, which continues for about a mile. The small synclinal to the eastward carries lower beds of Monroe shales, but they rise on the pitch, southward, and finally constitute the summit of the ridge to its southern termination. In this vicinity the anticlinal of Oriskany is exposed in the western slope of the ridge and along a small depression below. On the east side of the southern end of the ridge the pitch brings up the Oriskany quartzite, Helderberg limestone, Longwood red shales, and Green Pond quartzite in succession to the southward. The three first dip to the northwest, but the quartzite dips to the east, apparently from a small fault.

South from Greenwood lake there are two valleys, one extending along the Cambrian limestone belt and the other along the Monroe shales, with Kanouse mountain intervening. For some distance the structure is a west-dipping monoclinal, so far as I could find, but in the western valley, about half way to Newfoundland, it bears a low anticline. This flexure is well exhibited in the extensive exposures of Monroe shales at the small settlement of Postville, although its distinctness is somewhat obscured by the strong slaty cleavage by which the shales are traversed. The axis of the anticlinal rises to the southward, and at Newfoundland a sudden increase of pitch brings up Oriskany, Helderberg, Longwood, Green Pond and Archean rocks in rapid succession. This pitch of the beds is finely exhibited just west of Newfoundland, where the Green Pond quartzite and conglomerate rise into the northern end of a spur of Green Pond mountain. The dips are semi-quaquaversal and the beds exposed incline to the west, north, and east around the end of the mountain. A short distance south the crystalline rocks are brought up

in the core of the range, and by the erosion of the eastern limb of the anticlinal they have been bared of the Green Pond rocks over an enclosed area about a mile in length. The gneisses extend along the base of the mountain, and finally attain an elevation of 200 feet in its face, with cliffs of conglomerate above. The relations are shown near the center of section IX, plate 17. A mile and a half south of Newfoundland the pitch changes to southward, and the conglomerate in the eastern limb of the anticlinal gradually extends up the slope, and finally covers the crystalline rocks. To the southward the pitch increases, the flexure narrows, the ridge rapidly decreases in elevation and width and the Green Pond beds sink beneath the overlying formations. The flexure soon dies out in the area of Monroe shales southward. This spur of Green Pond mountain is separated from the main mountain by a narrow valley in a synclinal which is not of great extent.

Green Pond mountain rises on an anticlinal which begins under the lowlands just east of Newfoundland. The Longwood red shales are brought up in great force a mile south of Newfoundland, and then the Green Pond rocks, which rise rapidly into a high, rough ridge, presenting a steep rocky front to the east and a long slope to the west. The crystalline rocks soon come out along the eastern face of this ridge, constituting steep, rocky slopes, surmounted by a precipice of the conglomerate. The crystalline rocks gradually attain the crest of the anticlinal southward, and the pitch diminishing in amount, they continue in this position for a long distance, with ridges of conglomerate on either side. Green pond lies along this eroded arch, and along its western side is bordered by high cliffs of the Green Pond conglomerate. The outlet of the pond is to the south and it has cut a deep, narrow gorge in the crystalline rocks along the arch of the anticlinal. In Copperas mountain east of the lake, and southward to the end of this mountain, the Green Pond beds lie in a synclinal perched high on the crystalline rocks. North of the pond this synclinal pitches down, and finally occupies the valley lying between the northern end of Green Pond mountain and Copperas mountain. This pitch carries the Green Pond rocks across the low divide just north of the pond, and the synclinal valley contains Helderberg limestones over a considerable area south of Newfoundland, Oriskany quartzite at Newfoundland, and Monroe shales northward to beyond Postville, where the flexure dies out.

The northern end of Copperas mountain and Kanouse mountain its northern continuation, are monoclines of Green Pond rocks dipping westward beneath Longwood red shales, Helderberg limestones, Oriskany quartzite, and massive shales of the synclinal valley just described.

These mountains present steep rocky faces to the east and have relatively gentle slopes down the dip to the west.

*Faults.*—The differentiation of faulting and overlap in this region has been found to be especially difficult, so that some of the relations thought to be due to overlap or thinning may be the results of overthrust, and *vice versa*. A fault of considerable throw appears to extend along the western side of the belt, and there would be difficulty in accounting for some of the features without it. On the western side of Bearfort mountain the appearance of small areas of the flags and red shales underlying the Skunnemunk conglomerate is almost certainly due to variations in the throw of an overthrust fault, as shown in sections VII and VIII, plate 17. Southward to Bowling Green mountain the abrupt break between the steep slopes of crystalline rocks and the Monroe shales in the valley east, and the western termination of the Green Pond rocks in Bowling Green mountain are very probably due to the continuation of this fault. The immediate proximity of the fault was not observed, but no special features of increased plication were noticed in its vicinity. In Bellvale mountain and northward the fault may or may not be present, and the relations are probably due to overlap. Near the line of section V there is an exposure very near the contact of Oriskany quartzites and Hudson shales, in which it is seen that while an overthrust with low hade is possible, overlap is more probable. In the area shown in figure 2 a dislocation is suggested, but overlap is more probable.

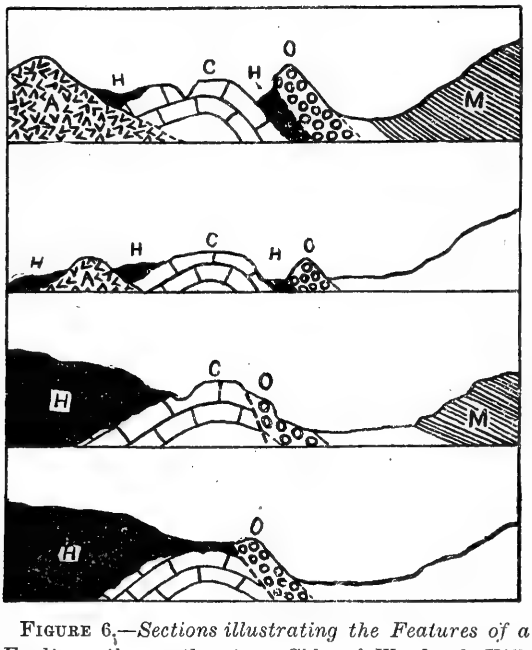


FIGURE 6.—*Sections illustrating the Features of a Fault on the southeastern Side of Woodcock Hill, Orange County, New York (looking north).*

*A* = Archean gneiss. *C* = Cambrian limestone. *H* = Hudson shales. *O* = Oriskany quartzite. *M* = Monroe shales.

On the east side of Woodcock hill the relations of a fault are exposed, but it may be a local feature entirely disconnected from the possible overthrust southward. Its relations are shown in the following figure, in which the sections are at approximately regular intervals for half a mile. The limestone is exposed abutting against the quartzite on the south side of a small stream which flows west across the southern end of Woodcock hill, and the hade is steeply to the east.

Whether the fault passes between the slate and quartzite, or the slate and limestone, northward, is not exposed, but the former appears more probable.

There is a small fault in the Green Pond quartzite on the southeast shore of Greenwood lake, as shown in section VII, but it is apparently only a local slip. Possibly it has greater throw southward and cuts off the several formations in the northern end of Kanouse mountain.

*Overlaps.*—There is a very great amount of overlapping in the Green Pond to Skunnemunk belt, and the phenomena throw interesting light on the oscillations of level and other conditions during the deposition of the several formations. I have alluded above to the difficulty in discriminating between overlap and overthrust, but the relations of the principal overlaps appear to be clear.

The Cambrian limestone lies on or against the crystalline rocks, with more or less arenaceous material intervening. It is overlapped by the Hudson shales in New York, which also extend to the crystalline rocks and abut against them. This relation is clearly exposed at many localities in Orange county, notably along the small crystalline knobs west of Skunnemunk mountain, which were islands in the early Hudson seas. A very fine exhibition of the contact of the shales and gneiss was found in the south bank of the creek at the south end of Woodcock hill, as shown in the second section from the top in figure 6.

The Green Pond conglomerate lies directly on the crystalline rocks over a wide area south of Newfoundland, and then extends across the edges of the Cambrian limestone to and over supposed Hudson shales south of Greenwood lake. In Pine hill it overlies the Cambrian limestone, with strong unconformity in dip, and about Cornwall Station it overlies the Hudson shales.

The Longwood shales are not known to overlap, for they merge into the upper part of the Green Pond rocks in all the exposures. The Helderberg limestone usually lies on and merges into the Longwood shales, but on the west side of Bellvale and Skunnemunk mountains it lies unconformably on Cambrian limestone, with no possibility of an intervening fault.

The Oriskany quartzites and conglomerates lie on the Helderberg limestone in New Jersey, at Cornwall Station, and in the locality two miles west-northwest of Monroe, but it overlaps or possibly is overthrust on older formations for the greater part of its course west of Bellvale and Skunnemunk mountains. Near the line of section V, plate 17, it lies on the Hudson shales, but, as suggested a number of times above, this may possibly be due to overthrust. In the small areas lying against the

crystalline rocks and Hudson shales two miles northwest of Monroe, as shown in figure 2, the supposed Oriskany quartzite quite clearly overlaps. Along the eastern side of Woodcock hill there is the fault and no exhibition of the overlap is seen at the surface. Along the base of the next Archean area south of Woodcock hill the quartzite appears to lie on the uneven surface of the gneiss without possibility of an intervening fault.

The Monroe shales lie in conformable sequence on the Oriskany beds in New Jersey, except just south of the southern end of Greenwood lake, where the quartzite may be lacking for some distance. They are very sharply separated by an abrupt change in the character of their materials, but present no special evidence of unconformity. There may possibly be a general break in the sequence in this region, represented by Caudi Galli shales and Onondaga limestone westward. North of Greenwood lake for many miles they appear to lie on the Cambrian limestone to the eastward, excepting for a short way southwest of Monroe, where they probably overlap on the crystalline rocks, although they are not exposed in contact. In the vicinity of Monroe and northward for some distance they appear to lie on the Cambrian limestone again, but their contact is covered by heavy drift. In Pine hill they lie on Helderberg limestone, but appear to overlap on the Cambrian limestone or even the crystalline rocks, northward for some distance. There is the possibility of a fault in this vicinity between the limestone and Monroe shales, but there is no positive evidence on this point. In Pea hill, near Cornwall Station, the shales lie in conformable succession on the Oriskany quartzite. Along the western side of Skunnemunk mountain they lie directly on Oriskany quartzites at several localities, and in the intervals, on Hudson shale and Cambrian limestone, but from the latter they may possibly be separated by a fault. Northwest of Monroe they overlap widely to the westward, as shown in figure 2, and are in contact with Oriskany, Helderberg, Hudson, Cambrian and Archean in succession. Along the west side of Bellvale mountain they are underlain by two lense-like masses of Oriskany quartzite and one of Helderberg limestone, and are in contact with Hudson shales, Cambrian limestone and Archean rocks in succession, possibly with a separating fault. Southward along the western side of Bearfort mountain they are cut out, in all probability by a fault as shown in sections VI, VII, and VIII on plate 17. They come out again in the wide synclinal region north of Milton and abut against the crystalline rocks, from which they are probably separated by the fault.

No overlap of Bellvale flags or Skunnemunk conglomerate are known, unless the contacts with the gneiss west of Bearfort mountain and on the southern end of Bellvale mountain are due to overlap and not to overthrust.

## Geologic History.

The trough in which the formations in the Green Pond-Shunnemunk belt lie, appears to be due to a narrow area of Cambrian limestone either deposited in a narrow inlet or, more probably, faulted down among the crystalline rocks. The erosion of this limestone wedge in early Paleozoic times afforded a long, narrow basin in which more or less shale was deposited in Hudson times. As this was followed by a period of uplift and erosion, in which more or less of the shales were removed, the position of the old shore line of Hudson deposition cannot everywhere be determined, and its southern termination is altogether in doubt. It probably extended at least as far south as Newfoundland. About Newfoundland and to the southward the crystalline rocks were bared at the beginning of deposition of the Green Pond beds, and were submerged by the general subsidence which inaugurated Upper Silurian deposition in eastern New York. As the conglomerates and quartzites are exhibited mainly along the eastern side of the basin and to the southward, it is suggested that the submergence was such that deposition was restricted to this area, for their relations to immediately succeeding formations indicate that they have not been widely removed by erosion. This period was continued by the deposition of the red shales of the Longwood series, the Helderberg limestones, and the Oriskany sandstones in continuous succession. The shales and limestone indicate increasing submergence and overlap, which appeared to have continued in the Oriskany deposition in part of the area. This condition in Oriskany times is indicated by the apparent almost general overlap of the Oriskany beyond the edges of the Helderberg beds west and southwest of Skunnemunk mountain, but that it is not general is shown by the absence of Oriskany deposits between the Helderberg limestone and Monroe shales in Pine hill north of Monroe, and at the locality on the west side of Bellvale mountain. The coarseness of the deposit indicates an abrupt change of conditions, which abruptly terminated the deposition of the Helderberg limestones. As a change of this character usually immediately follows uplift the relations here are somewhat anomalous. They may be due to increased submergence having given access to stronger currents which brought in the coarse materials. This, however, is merely a suggestion.

The Monroe shale deposition was attendant on increased submergence and the deposits overlapped the preceding formations and the crystalline rocks in part. Probably they were laid down over a wide area, for they have since been widely removed by erosion.

The Skunnemunk conglomerate probably overlapped the crystalline

rocks, and also the Green Pond conglomerate, for its materials appear to have been derived from both of these sources. Possibly its quartzite pebbles were not derived from Green Pond beds in this basin, but came from other regions. The original thickness and extent of the Skunnemunk conglomerate is not known, for it has been deeply eroded.

Whether the several Upper Silurian and Devonian members originally extended continuously to the great areas to the north and west is not known, but from the similarity in characters and faunas it is supposed that they were deposited in inlets of the same general water areas.

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# TRIAS AND JURA IN THE WESTERN STATES*

BY ALPHEUS HYATT

(*Read before the Society December 28, 1893*)

CONTENTS



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I also gratefully acknowledge the assistance afforded me both by Alexander Agassiz, Director of the Museum of Comparative Zoölogy, who permitted the use of the valuable collections of that museum, and by Professor J. D. Whitney, whose donation of some of Gabb's types was of essential importance in settling the age of the rocks in which they were found.

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## Introductory.

The following abstract gives the latest results of the examination of collections of fossils, chiefly made by the United States Geological Survey, which have passed through my hands within the past few years.

The descriptions of the species mentioned and of others previously noted in my paper, "Jura and Trias at Taylorville, California,"* will be published by the United States Geological Survey when the proper illustrations can be prepared.

## American and Sailors Canyons, California.

### *THEIR FAUNAS.*

*Monotis Beds.*—The presence of the Trias above the Carboniferous in American and Sailors canyon south of Cisco was at first considered certain from the presence of the *Monotis* beds containing two new species, *M. semiplicata* and *symmetrica*, but further information is essential before this can be admitted. According to the observations of Dr Curtice these beds lie between the Carboniferous and the *Daonella* beds.

*Daonella Beds.*—The *Daonella* beds contain several species of that genus, heretofore supposed to be confined to Triassic strata in Europe and in this country. They immediately underlie the beds containing forms of Ammonitinæ described below, and also ascend sporadically into that fauna in the rocks above Sterrets mine in Sailors canyon.

There is one species, *Daonella subjecta*, occurring alone in a piece of black shale, which may indicate the presence of a lower bed distinct from that in which the other species mentioned below were found, but, according to our existing information, they must be here included in the same horizon.

Ordinarily the species of *Daonella* occurring immediately underneath the *Ammonites* bed would also be regarded as exclusively Triassic, and

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* Bulletin of this Society, vol. 3, pp. 395–412.

unquestionably would be placed in that system but for their association with Ammonitinæ.

*Daonella böchiformis* is a close representative of the *D. böchi*, Mojsisovics, which belongs in Europe to the passage beds between the Muschelkalk and the Noric series. The type of *Daonella* to which this and the following species belong indicates the presence of the primitive forms of the group of *D. moussoni*, as defined by Mojsisovics, which begins in the Muschelkalk in Europe. There is also another form of *Daonella* associated with the two mentioned here, but it is so close to *D. böchiformis* that for our present purpose it may be considered a variety of this species.

*Daonella cardinoides* is a distinct species, but a close ally of *D. böchiformis*, and therefore belongs to the same section of the genus. Specimens of *Daonella* are found sporadically also in what must be considered younger beds, containing compressed remains of Ammonitinæ, which have presented a problem of a very interesting character. This was also the geologic position assigned by Dr Lindgren and Dr Curtice, who first collected them and studied the geology. At first sight they appear by their ornamentation to belong to the Lias. Unluckily the process of fossilization has entirely obliterated the sutures, and the most careful and repeated observations have failed to discover any traces of these parts. The representation of external form and characteristics is so close between some Ammonitinæ of the Trias and Lower Jura that one cannot be sure whether a given fossil occurs in the Upper Trias or Lower Jura unless the sutures are present, with, of course, the exception of a certain list of common and well known forms. It so happens that in this entire collection there are but few which can be said to belong to this last mentioned class.

*Ammonites Bed.*—The occurrence of what I have called *Peronoceras* (?) *americanum* at Sailors canyon and some other forms introduces a style of ornamentation not yet found below the uppermost beds of the lower Lias, but these fossils are not well enough preserved to be determinative.

The Aptychi are of the bivalvular rugose type, and they would be usually considered as supporting the opinion that these beds were not older than the middle Lias and perhaps not older than upper Lias. Nevertheless it must be remembered that a bivalvular *Aptychus* was found in the Devonian of the Eifel and was described by D'Archiac and De Verneuil,* and that a single Anaptychus also occurs in the Devonian, both of them being associated with Goniatitinæ. The argument there-

* This *Aptychus* is bivalvular, but has a peculiar shape in that the valves are divaricated along the median line and near the outer convex edge. Their internal edges, in other words, are not closely approximate as in other bivalvular Aptychi. The lines of growth are described as indistinct undulating lines of growth, and the figure shows that it had a smoother surface than the rugose Aptychi of the Jura to which the Sailors Canyon Aptychi can be closely compared. See Fossils of the Older Deposits, etcetera, Trans, Geol. Soc. Lond., sec. 2, vol. vi, pt. 2, pl. 26, fig. 9.

fore that the Aptychi found in the *Ammonites* bed of Sailors canyon prove the age to be Liassic is not conclusive. These earlier opercula were all found to be carbonaceous, and consequently it is inferred that they must have had a horny or tough cuticular basis.

A peculiar leathery or horny and univalvular operculum called the *Anaptychus* was introduced in the Arietidæ of the lower Lias and continued in the middle Lias, and it has been reasonably supposed that these were the forerunners of the calcareous bivalvular opercula of the shells of the succeeding stages.

The bivalvular rugose Aptychi at Sailors canyon are represented solely by impressions, and consequently their exact constitution cannot be proved. Whether they were really calcareous like the similar rugose forms of the Lias and later Jura or whether they were of a horny texture must remain undecided, and this is a possible stumbling-block in the way of any opinion based solely upon them.

It must also be noted that if this fauna be Triassic, it is remarkable for not containing any of the characteristic cephalopods of that system, and none exactly comparable with those of any other Triassic fauna, either in this country or in Europe.

The specimens of Ammonitinæ found by Dr Curtice below the tuffs that form the summit of Snow mountain, the highest fossil locality in American canyon, are similar in part to those of Sailors canyon, and indicate a somewhat distinct yet connected and probably younger Ammonitoid fauna.

*Gryphæa Bed.*—The specimens described as *Gryphæa*, and found in rocks supposed by Dr Curtice to be younger than the *Ammonites* beds of Sailors canyon but older than those of Snow mountain, give evidence for the Liassic age of these rocks, true *Gryphæa* not having been hitherto found below the lower Lias.

### *AGE AND FAUNAL RELATIONSHIPS OF THE TWO AREAS.*

Although it is safe to decide positively with regard to the relative age of the different strata of the Sailors canyon series and that the *Monotis* and *Daonella* beds contain forms usually regarded as Triassic, the facts just recited are of such a nature that the age of the beds containing Ammonitinæ and Aptychi cannot be asserted except within certain limits. Whether they are exclusively upper Triassic or exclusively Liassic, or a mixture of the fossils of both these faunas, must remain undetermined until the sutures of these fossil shells can be discovered. It is, however, obvious that there are, so far as they have been explored, no fossil beds in American or in Sailors canyon which are younger than the upper Lias.

By comparing the statements made in this paper with the table given in my article, "Jura and Trias at Taylorville, California,"* it will be seen that the Swearinger slates were divided into *Monotis* beds, *Daonella* bed, *Rhabdoceras* bed and *Halobia* bed, and the whole group was referred to the Upper Noric.

The succession of the *Monitis* and the *Daonella* bed is similar in American and in Sailors canyon, but above this, parallelism ceases.

The development of unquestionable Triassic types in the Taylorville region leaves no room for doubting the system to which the rocks containing them belong, and they also indicate the particular series to which strata may be referred. These differences and the entirely distinct species of the two localities, even in the genera *Monotis* and *Daonella*, show that there were two distinct faunal areas, and that there could have been no communication between them during the time of the deposition of the *Monotis* and *Daonella* beds, even if it is admitted that they were contemporaneous in deposition, an opinion which cannot be maintained by any facts now known.

## Trias of Nevada and Idaho.

The Whitney collection of fossils contains a specimen of *Arcestes* (*ausseanus*) *gabbi*, Meek, from Volcano mining district, thirty miles southeast of Walkers lake, Nevada, which is quoted by him † as characteristic of the Trias at that locality, and also a slab of *Daonella* having the same catalogue number and apparently from the same locality. This species is identical with the *Halobia dubia*, Gabb, which is equivalent to *Halobia* (*Daonella*) *lommeli*, Meek.‡ The Trias is therefore present at this locality, and these two forms indicate a fauna similar in part at least to that of the Trias of Humboldt county, Nevada. There is also in this collection a few fossils from New pass, Desatoya mountains, Nevada, indicating that there is a rich Triassic fauna at this locality of approximately the same age as that of the Star Peak range, that is to say, Muschelkalk.

The following is quoted from my former paper, "Jura and Trias at Taylorville, California:" §

"The Trias of Idaho (Aspen mountains, near Soda springs) has a well-marked Triassic fauna, with fossil cephalopods recognized in Europe by Mojsisovics, Steinmann and Karpinsky as belonging to the lower part of the Triassic system, and, after careful reëxamination of the fossils, I find strong grounds for thinking that this opinion is probably correct. This fauna appears to be more nearly the equiva-

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* Bull. Geol. Soc. of Am., vol. 3, p. 412.

† Descriptions of Secondary Fossils, etc: Am. Jour. Conch., vol. v, p. 5.

‡ Exploration of the Fortieth Parallel, p. 100, pl. 10.

§ Bull. Geol. Soc. Am., vol. 3, p. 400.

lent of that of the Werferner beds of the middle Buntersandstein of the German Trias than of any other.

"The Trias of the Star Peak range, in the Humboldt region, Nevada, contains an unmistakably younger fauna. Before reading the similar opinion of Mojsisovics, published in his superb work 'Die Cephalopoden der Mediterranean Trias-Provinz,' I had arrived independently at the same opinion, that this fauna belonged to the Muschelkalk and not to the younger Saint Cassian stage, as formerly supposed. When the species are properly published the parallelism with the Muschelkalk will be readily seen, since well preserved cephalopods are abundant.

"The Trias of Taylorville is quite as interesting as that of the other two localities, and it is very suggestive that its age, as indicated by the fossils, is that of the Noric and Karnic series in the upper Trias."

## Lias in California, Nevada and Oregon.

The discovery of Gabb's type of *Ammonites nevadanus* and the confirmation of the reference of this species made by the author in "Genesis of the Arietidæ," to the European genus *Arnioceras* of the lower Lias involves several points of great interest.

The type specimen is not itself tuberculated, but it is accompanied by a specimen labeled "*Ammonites nevadanum*," which has been more correctly redescribed by the author as *Coroniceras claytoni*, thus referring it to another equally well known lower Liassic genus of western Europe.

The following statement is quoted from page 410 of my pamphlet, "Jura and Trias at Taylorville, California":

"The lower Lias, containing characteristic Ammonitinæ, one species of which (*Arnioceras humboldti*), was described in my 'Genesis of the Arietidæ,' occurs in the region formerly called the American district, Nevada, probably in the southern portion of the Star Peak range. There are also fossils in the collection of the mining bureau at San Francisco labeled as having been gathered in the Santa Fé district, Esmeralda county, Nevada, and Inyo county, California. These would not be worth mentioning were they not reported from places lying in the direction of the general strike of the Jurassic strata, and also in perfect accord with the presence of *Arnioceras humboldti*. One species is a form of *Vermiceras* allied to *V. conybeari* of the faunas of the lower Lias in Europe, which I propose to name *V. crossmani*.* The second fossil, from Inyo county, was considered by me in the work already quoted to be identical with *Arnioceras humboldti*, but a reëxamination of the same specimens, made in the summer of 1891, has satisfied me that this was an error. The costæ are more closely crowded, and there are slight constrictions at intervals on the whorls of the nealogic (adolescent) stages. These disappear later, giving way to slightly arcuate costæ, which also differ from those of *Arnioceras humboldti*.

* The type is number 4989, collection of the State Mining Bureau, San Francisco, California, collected by J. H. Crossman. There is one specimen with the internal whorls and part of a living chamber in good condition, and two large fragments more compressed. It is a species having numerous whorls, as in the more generalized forms of the genus, straight numerous costæ without tubercles on the geniculæ, but the latter are prominent on the outer whorl and look as if they might have tubercles in later stages. The abdomen is channeled and keeled.

I therefore propose for this peculiar form the name of *Arnioceras woodhulli*.* These facts all tend to the conclusion that the lower Lias, having certain forms of undeniable European facies, occurs in western and southwestern Nevada and perhaps in California east of the crests of the Sierra."

These conclusions have been confirmed not only by the above but also by the following facts:

Through the kindness of Mr J. S. Diller I received from Professor Thomas Condon, of the State University, Eugene City, Oregon, a small collection of fossils of great interest. These specimens are labeled as having been collected by Professor Condon on Beaver creek, a tributary of Crooked river, in the Blue mountains of eastern Oregon. They show that the fauna of the Hardgrave sandstone occurs at this locality.

The matrix is red sandstone similar to the rock at Taylorville. The close affinity and probable identity of *Pholadomya nevadana*, Gabb, from Beaver creek and what has been hitherto named *P. kingi*, Meek; the identity of *Pholadomya multilineata* in this locality and near Volcano, and, finally, the citation by Gabb of the occurrence of *Pecten acutiplicatus*, an almost unmistakable form, at this last named place shows that the Hardgrave sandstone or upper Lias exists at these widely separated localities to the east of the Sierra Nevada, as well as at Taylorville, on the western slope of this range. Gabb, in the same publication, describes and figures as from this locality *Turbo regius*,† *Turbo elevatus*, *Pholadomya multilineata*,* *Pholadomya nevadana*, *Goniomya aperta*, *Cardium arcæformis*, *Astarte appressa*, *Plicatula perimbricata*,† as new species allied to Jurassic forms. The Ammonitinæ show that the lower Lias certainly exists at this locality near Walkers lake, in southwestern Nevada, and that it probably runs from thence southward into Inyo county and northward into the southern part of Humboldt county, as stated above. It seems highly probable also that the Hardgrave fauna exists in Esmeralda county, Nevada, thirty miles southeast of Walkers lake, in close conjunction with the lower Lias, and at Beaver creek in the Blue mountains of eastern Oregon, and it is obvious that there was no barrier between these three littoral faunas at the time of the deposition of the upper Lias of Taylorville and that these three basins were contemporaneous and connected.

I have not been able to add anything in this paper with regard to the middle Jura or Oolites beyond what has been given in the paper quoted above.‡

* The type is in the collection of the State Mining Bureau, San Francisco, number 7642, Inyo county, California, collected by D. S. Woodhull.

† The types of those marked with a star have been found in the Whitney collection, Museum of Comparative Zoölogy. See Am. Jour. Conch., 1869.

‡ Jura and Trias at Taylorville, California, p. 410.

## UPPER JURA IN CALIFORNIA.

### *AMMONITINÆ.*

*Cardioceras dubium.*—One lot of fossils from Texas ranch, Calaveras county, collected by Dr G. F. Becker, is largely composed of Ammonitinæ of one species, described below as *Cardioceras dubium*, and is found associated with Aucellæ. The sutures are present, and although much distorted, give indications of affinity of considerable value. The evidence shows that it is a species of *Cardioceras* and that the age of the slates in which it occurs is Upper Jurassic. The nearest affine or representative of this is a peculiar variety of *Cardioceras alternans*, sp. Von Buch, which is found in the Oxfordian and only in the Russian fauna, and is there also accompanied by the first representative in that region of the genus *Aucella.*

*Perisphinctes virgulatiformis.*—*Perisphinctes virgulatiformis* was found by Dr Curtice near Reynolds ferry, Stanislaus river, opposite Bostwicks bar.* This species has all the peculiar external features and the sutures also of a characteristic series, the Virgulatus group of this genus, which occurs only in the Upper Jura in Europe. The nearest affine is a species from the Solenhofen slates, described by Quenstedt as *Ammonites planulatus silicius.*

*Œcotraustes denticulata.*—*Œcotraustes denticulata* was also found at Reynolds ferry by Dr Curtice, and this is a member of the smooth-whorled section of the genus, having a denticulated keel. It is allied to *Œcotraustes lochensis*, sp. Oppel. of the Oxfordian, and, like the preceding, indicates the Upper Jura.

*Associated Forms.*—Associated with these Ammonitinæ at Reynolds ferry there are some species of *Cerithium*, of no great value in determining the age of the rocks; also some *Pelecypoda*, too imperfect to be of use. There is also from this locality an Aviculoid, which may be a near ally of the peculiar shell first described as *Aucella impressæ*, Quenstedt, from Upper Jura of Wurtemburg. Unluckily I have not been able to determine whether the best specimen had an anterior ear like the shell described by Quenstedt or whether the mark I saw was part of a tooth. This so-called *Aucella impressæ* of Quenstedt, as stated by Lahusen, is certainly not a true *Aucella*, nor even a member of that genus.

*Perisphinctes filiplex* (?).—*Perisphinctes filiplex* (?) sp., Quenstedt, found on the south bank of Tuolumne river at Moffats bridge, on the Stanislaus river near canyon opposite the mouth of Bear creek and six miles from

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*A "bar" is a term used in the west to indicate a locality on a river where placer mining is carried on.

Copperopolis, is very generally distributed and gives also positive evidence that the Gold belt forms of *Perisphinctes* belong largely to the group of *P. alternans* of the Upper Jura of Russia.

Gabb's type of *Ammonites colfaxi* and the positive information it affords that it is a species of *Perisphinctes*, together with the description of *Perisphinctes mühlbachi*, another allied, but new species, from the black slates of the same series of rocks southward, in Eldorado county, and specimens of the species mentioned by Whitney * as coming from near Folsom, Sacramento county, which is a variety of *mühlbachi*, all show that the slates of the Gold belt are of Upper Jurassic age. This result is strengthened by the obvious affinities between *mühlbachi* and the *Perisphinctes* found in the slates of Tuolumne and Calaveras counties to the south of the localities first mentioned.

### *PELECYPODA AND GASTEROPODA.*

The Pelecypoda and Gasteropoda from these localities are too fragmentary to be of much value, except the *Amusium aurarium*, Meek, (?) which may be identical with Meek's species, but it is not perfectly symmetrical, as in Meek's figure, and some doubt is created by this fact.

The remains of Belemnitinæ were found at localities in Mariposa county and near Greenwood, in Eldorado county. The forms are closely allied, if not identical, in all the localities explored, but the conditions of these fossils are very unfavorable for exact comparison. They do not help us to determine the age of the rocks, since I am not able to compare them clearly with species from other places.

### *AUCELLÆ.*

*General Remarks.*—The remains of Aucellæ are, as a rule, flattened by compression, but the markings and forms of the shells can be studied in detail. There is, of course, considerable danger that one may be sometimes representing the results of compression as specific differences, but I know of no way of avoiding this except by the use of large numbers of specimens, and there has been no dearth of materials. The gentlemen who collected them have had the true spirit of good collectors and filled their bags whenever they had an opportunity. The following remarks are abstracts of results, which will be given in more detailed descriptions of the species.

*Aucella erringtoni.*—*Aucella erringtoni*, Meek, var. *arcuata*, was found at three places, on south bank of Tuolumne river at Moffats bridge, on Stanislaus river opposite mouth of Bear creek, and six miles from Copperopolis on road to Sonora and grade to Angels creek.

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* Auriferous Gravels, p. 37.

This is the extreme form, and the shell is in some cases apparently smooth and in others marked by longitudinal striæ. Its nearest affine is the *Aucella mosquensis*, Keyserling, as figured and described by Lahusen from the lower Volgian in the Upper Jura of Russia. *Aucella pallasi*, Keyserling, is sometimes slightly striated and very like this species in general aspect of the left valve, but the characteristic of the hinge line of the right valve enables one to separate them easily from each other. The explanation is simply that the range of morphic modification in the whole group of the genus, and likely to occur in every species, is from Avicula-like shells with circular outlines to forms with narrow arcuate left valves; but while two forms may be similar in the shape of the left valve, they may entirely disagree in the shape of the hinge lines of the less modified right valves. This is not uncommon in highly variable asymmetrical Pelecypoda, and in all of these the characteristics of the hinge are admitted to be determinative of the species.

*Comparison of Aucellæ.—Aucella concentrica*, Fischer (not Keyserling), collected at Amackshack bay, Alaska, may be the same as this species. The narrow smooth form of *Aucella piochi*, Gabb, from Riddles, Oregon, sent me by Mr Diller as coming from the Knoxville group, appears to be very similar to this species. This last is sufficiently distinct from the stout plicated form of *Aucella piochi* of the Shasta group to be separable on biologic grounds, and it is probably stratigraphically distinct, the mass of the former occurring below the stouter form of the latter, as has been shown by Messrs Stanton and Diller. The history of these two forms accords exactly with the geologic conformability and unbroken succession of the strata of Knoxville and Shasta groups, as stated by Mr Diller. After a close examination of the large collection in the National Museum I came to the conclusion that, as a rule, the narrow form of *Aucella piochi* occurred dissociated from the broad plicated form described by the same name, and accordingly furnished Mr Diller with a list of localities to test in the field the question of superposition.

The following is a part of his field report for 1893 subsequently sent to Mr C. D. Walcott,* which he kindly permits me to publish:

"After studying the collection of Aucellæ at the National Museum last year, Professor Hyatt expressed the opinion that there were apparently two types of Aucella, one Cretaceous and the other Jurassic. Both, however, were from the Knoxville beds. He gave me a list of localities at which the stout or Cretaceous forms occur, and also the localities at which the slender or Jurassic form occurs; and upon examination I found that all the Cretacic forms come from beds overlying the Jurassic forms. The investigations made this year by Mr Stanton and myself point in the same direction, but I am not sure that the two forms are not intermingled. Mr Stanton made collections of Aucellæ at a number of places, and

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* Chief geologist, U. S. Geological Survey.

will be able, when the collections arrive and he studies them, to satisfactorily solve the problem.

"There is one point, however, concerning which there is no doubt, namely, that both forms occur in the Knoxville beds near together. They are in the same series of sediments laid down without any interruption, and if one is Jurassic and the other Cretaceous, then there is no break between the two, and the Knoxville beds belong to both systems.

"The relation of the Knoxville and Mariposa beds is not yet satisfactorily determined, and I have no evidence concerning their relation. The fact, however, that there is no break in the Shasta-Chico series makes it more probable that the Knoxville and Mariposa beds are unconformable."

The opinion which Mr Diller quotes that the smooth, narrow form of *Aucella piochi* is probably Jurassic was founded upon the supposition, which then seemed to me reasonable, that it was identical with the striated, narrow form described in this paper as *Aucella erringtoni* var. *arcuata*. The late explorations of Mr Stanton and Mr Diller have, however, demonstrated, what the collections of the National Museum had already led me to suspect, that these two were distinct. Not only are nearly all the fossils of the former in the collections of the National Museum smooth, but I am informed that out of the hundreds examined in the field by these two gentlemen and brought home by them only very few have yet been found with striations like those of the Gold belt fossils. Any one familiar with the slight differences that characterize species of this genus will at once see, when the specimens are placed side by side, that not only are the Knoxville forms of *Aucella piochi* deficient in striations, but they have not the broad posterior wing of the *Aucella erringtoni* var. *arcuata* and the beaks are more prominent, extending further beyond the hinge line, and proportionately narrower.

Even if it should be admitted that these two species were connected by intermediate forms, this fact would only show that the migration of the Aucellæ took place from the more southern basin into the more northern one, and give a solid biologic argument for the conclusion that the Gold belt slates are older than the Knoxville. The connecting forms are confined to one variety of *Aucella erringtoni* var. *arcuata* having striations, and to one variety of extreme rarity in the Knoxville, *Aucella piochi* of the slender variety, having striations. The remaining varieties and species are distinct. The *Aucella piochi* has its own peculiar series of forms, which, as will be shown by Mr Stanton, pass from the slender form in the lower Knoxville into the stouter constricted shells of the upper Knoxville, and are there associated with Cretacic species of Ammonitinæ. The Aucellæ of the Mariposa region have their own peculiar series of broad and rounded forms having affinities for the slender *Aucella erringtoni* var. *arcuata*, but they evolve along different morphic lines from

*Aucella piochi*, and are associated with Ammonitinæ of the group of *Perisphinctes* of the Upper Jurassic facies, and so far not a single species of this genus has been found in the Knoxville. The conclusion, therefore, that the Knoxville slates contain a distinct and younger fauna than the Gold belt slates rests upon a very strong basis of paleontologic evidence.

*Aucella elongata.*—*Aucella elongata* found near Reynolds ferry is a broad and also excessively elongated shell and very distinct from *Aucella erringtoni* var. *arcuata* in the characteristics of the outline, the constancy of the longitudinal striation, and the shape of the hinge line in the right valve. The representative form of this species, as stated by Lahusen, in Russia may be *Aucella bronni* from the zone of *Cardioceras alternans*, in the Upper Jura of Russia.

*Aucella aviculæformis*, from several places in Calaveras county, has an outline somewhat like *Avicula*, with a broad posterior wing. The young shells are similar to those of *Aucella obicularis*, but they become more elongated by growth. Some of Eichwald's species from Alaska,* as figured by him, certainly appear to have been identical with this California shell in outline, but they are not striated. There may be close affinity between this species and *Aucella mosquensis*, Whiteaves, of Queen Charlottes island, as stated by Lahusen, and also with *Volgensis*, Lahusen, but in all of these supposed congeners longitudinal striæ are absent in the drawings, at least, and the posterior wings of the valves are not well developed.

*Aucella obicularis.*—*Aucelia obicularis*, from all the mentioned localities in Calaveras county, has an extremely circular outline, and the hinge area of the left valve is correspondingly modified, the anterior part being very gibbous and protuberant. Eichwald † has figured a similar form from Alaska, but here again our species differs in being striated.

*Conclusions based on Study of Aucella.*—The evidence gathered from the study of *Aucella* shows that, while forms of this genus in the California slates of the Mariposa series are all more or less distinct on account of the prevalence of the strong longitudinal striæ, they represent two groups of Aucellæ as they appear in Europe. It is obvious that the forms which I have named *Aucella orbicularis*, *aviculæformis* and *elongata* have a broad hinge and gibbous oral or anterior outline in the right valve like that of the *pallasi* type, whereas *Aucella erringtoni* var. *arcuata* has a narrow hinge line, with the umbo more nearly central, as in the *Mosquensis* type of that genus, and it is the latter alone which approximates in outline to the narrow form of *Aucella piochi*, Gabb, prevalent in the Knoxville series.

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**Aucella palassi*, Eichwald: Mangischalk et Aleuts Inseln, pl. 17, f. 3–4, and Mosquensis, f. 13–14.
† Mangischalk et Aleuts Inseln, pl. 17, f. 2.

There seems to me, therefore, to be good grounds for the following conclusions:

1. That, laying aside the vexed question of what constitutes a species, there are here three distinct and probably connected forms, beginning with and perhaps evolved out of *Aucella erringtoni* var. *arcuata*, or some common form represented most nearly by it, which migrated along a changing sea bottom in which sediments were accumulating.

2. That as the sediments accumulated the *Aucella erringtoni* var. *arcuata* gradually shifted its location chorologically northward and chronologically upward into the Knoxville basin, changing as it migrated into *Aucella piochi* of the slender form.

3. That in the same basin this species remained, migrating chronologically with the accumulation of sediments and gradually changing into the stouter, constricted form known under the same name, but stated by Messrs Diller and Stanton to occur only in the upper part of the Knoxville slates.

I do not state here the exact lines followed in this migration, but only the result in the final arrival of the modified form in the Knoxville basin.

Stoliczka's* figure of a form of *Aucella* discovered in the Tagling limestone, lower Lias of India, certainly appears to support this opinion, and the discovery shows that this genus originated earlier in the Jura than has been supposed and must have traveled northward in Asia, as it did in this country. It is to be noticed also that this Liassic shell has fine radiating striæ like our own Upper Jurassic species in California.

It will be remarked here that I take a position different from that generally adopted in Europe and oppose the inference that the northern Aucellæ migrated to the southward.

Whether there is nonconformity between the Knoxville and Gold belt slates is of no consequence to this argument; it is just as sound in case of conformity as of nonconformity. If there is conformity, probably varieties of *Aucella* will be found having not only identical striations, but other characteristics identical with those of *Aucella erringtoni* var. *arcuata* in the lowest part of the Knoxville group or below it in rocks not yet explored.

### *CONCLUSIONS DERIVED FROM ASSOCIATIONS AND COMPARISONS OF FAUNAS.*

These conclusions are based upon Aucellæ, but the collateral evidence of associated forms in the different faunas gives additional strength to the same opinions.

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* *Aucella leguminosa*, Stoliczka: Mem. Geol. Survey of India, 1866, pl. 8, f. 8.

The Ammonitinæ associated with *Aucella erringtoni* are peculiar species of *Perisphinctes* and of other genera of the uppermost Jurassic more nearly allied to the similar species of that genus found in the Aucella-bearing rocks of central and northern Russia than those of any other fauna. The uppermost Jura in Europe, Asia, India and South America is characterized even where no Aucellæ have been found by the prevalence of *Perisphinctes*, and we can now add North America to this list.

Having, through the kindness of Messrs Diller and Stanton, been permitted to study Ammonitinæ collected by them in the upper Knoxville, I can now say that the fauna of the entire Gold belt series of slates have nowhere been found to contain a species similar to those of the numerous Ammonitinæ found in the Cretacic faunas of the upper Knoxville and Shasta groups. The fact that some genera usually pass from the uppermost Jura into the Cretaceous is of no consequence in this connection and can be ignored.

The only specimen about which I am now doubtful is that named *Olcostephanus* (?) *lindgreni*. This shell has characteristics which might occur in either an Upper Jurassic or early Cretacic shell, but its nearest congener appears to be one described as occurring in the youngest Jura of Russia. The doubt in this case arises from the imperfect preservation of the umbilicus and the importance of the characteristics thus obscured or destroyed for the exact determination of the affinities in the shells of this genus, the species of which occur both in the Jura and in the Cretaceous faunas of Europe.

Aucellæ occur in the Russian faunas accompanied by *Cardioceras alternans* (allied to our *Cardioceras dubium*); in the Oxfordian of central Russia; in the later horizons of the Jura further north, with a limited number of *Perisphinctes*, and in the highest and youngest members of the Jura in thick deposits, of which the Aucellæ are almost the only fossils. This is parallel with the history of the Aucellæ-bearing rocks of California as compared with those of Knoxville. Lastly, Aucellæ of similar forms to those of the plicated broad shells of *Aucella piochi* occur in the recognized lowest Cretacic faunas of Russia associated with numerous Ammonitinæ of many genera, as they do in the upper Knoxville and Shasta groups.

I have referred above to the similar relations existing between the Alaskan species of Aucellæ and some of these forms. Eichwald distinctly asserts the association of these Alaskan species with Ammonitinæ, but his text does not confirm this statement, since he gives no local lists and makes nowhere any direct assertion that they occurred in the same slabs with Ammonitinæ. Grewingk did not find *Aucella* associated with the species of Ammonitinæ that he collected, nor has Dall in his collec-

tion of Aucellæ described by Dr White.* This negative evidence coincides with the facts brought to light by the examination of the Ammonitinæ of Alaska and those of mount Jura and the Black hills. All the fossils so far described from these localities belong to faunas older than those of Europe in which *Aucella* occurs.

The fauna of the Black hills, acknowledged to be Jurassic by every one but Whiteaves, is in part apparently synchronous with that of the Aleutian islands and Alaska, as described by Eichwald and Grewingk. The differences between the Upper Jura fossils in both are simply such as might occur between any two different basins situated in approximately contemporaneous faunas. This parallelism and the additional negative evidence of the collections of Grewingk and Dall led me to suspect that Eichwald might possibly be wrong in stating that the Aucellæ of Alaska were associated with the Ammonitinæ of the Upper Jura which he describes.

The faunas of Alaska, the Black hills, and Aurora, Wyoming, correspond in part, at least, so far as the marine invertebrata are concerned, to that part of the Jura known in Russia as the zone of *Cardioceras cordatum*, in the lower Oxfordian. This might of course in this country contain species of Aucellæ, but in that case they ought to be forms of that genus quite different from any found in Europe and representing older and more primitive types, or else close allies of *Aucella elongata* or other striated species of our zone of *Cardioceras dubium*.

The faunas of mount Jura at Taylorville for the most part, as stated above, are older than those in which Aucellæ are found in Europe, and so also is that described by Dr White from Alaska. Supposed Aucellæ have been found in the Upper Jura of western Europe, but, as stated by Lahusen, they are not really species of this genus.

In Russia, according to Pavlow † and other authorities, notably Lahusen, the zone in which *Aucella* makes its first appearance, that of *Cardioceras alternans*, immediately succeeds in time the zone of *Cardioceras cordatum*, now more properly designated *Quenstedioceras cordatum*, both being in the Oxfordian, the former unquestionably the younger. There is therefore a sound basis for the conclusion that the Jura of the Gold belt is younger than that of the Black hills and in part, at least, than that of Alaska and the Aleutian islands. The direct evidence afforded by the Ammonitinæ of the rocks at Texas ranch, in Calaveras county, where *Cardioceras dubium* represents *Cardioceras alternans*, places these rocks as the equivalent of the upper Oxfordian in Russia.

At the Stanislaus river locality there occurs *Perisphinctes virgulatiformis*,

* Bulletin no. 4, U. S. Geological Survey.

† Syst. Jurass. de l'Est de la Russie: Bull. Soc. Geol. France, 3d ser., vol. xii, 1883–'84, p. 686.

a species of the same group as *Perisphinctes* of the Solenhofen slates, and *Œcotraustes denticulata*, another prevalent form in the youngest faunas of the Jura in Europe. This association is again similar to that of the faunas in Russia, since the Volgian, being in the Portlandian and occurring just above the Oxfordian in that country, is equivalent, so far as position is concerned, in part at least to the Solenhofen slates. This comparison is sustained by the obvious fact that in the fauna of this and other similar localities the genus *Perisphinctes* is the prevalent form of the Ammonitinæ associated with Aucella, as is also the case in the Russian fauna supposed to be of corresponding age.

I have thought it best, as may be seen above and further on, to consider the rocks of the western slopes of the Sierra Nevada containing *Perisphinctes*, such as those near Greenwood and Colfax, as provisionally of the same age, although they contain no Aucellæ. The relations of the faunas of localities mentioned presents also, as regards the intimate relations and probable chronology of the appearance of the different species of Aucellæ, a remarkably close parallel with what Lahusen has worked out in Russia.

The Stanislaus river locality has only *Aucella elongata*, *aviculæformis* and *orbicularis*, all of which belong to the Pallasi type of Aucella, that which appears first in Russia. At the locality on the south bank of Tuolumne river *Aucella erringtoni* var. *arcuata* makes its appearance, and this is the representative of the Mosquensis type, which also in Russia appears after *pallasi* and *bronni*.

The foregoing are merely tentative comparisons, so far as the relative chronology of the beds of the Gold belt slates are concerned. In order to give a final opinion more materials are necessary and some of the geologic details of the relations of the rocks in these different localities should also be ascertained. They will, however, it is hoped, serve to draw the attention of geologists and collectors to the need of making collections as extensive as possible in every locality, and to the importance of noting the exact horizon of each fossil, even though it occurs in immediately contiguous and conformable strata in the same bank or quarry and appears to them in the field to be the same species.

## Classification of the Jura.

The full classification of the parts of the Jura in this country remains, of course, to be worked out, but for general purposes and as a provisional guide I have found that the general classification given by Steinmann* is the most satisfactory. Probably no strictly European classification will suffice, but it seems clear that we can distinguish in the system of the

* Elemente der Paleontologie, Leipzig, 1890.

Jura the following series: Lias or Lower Jura, Oolite or Middle Jura and Malm or Upper Jura.

In the Lias we have the Lower Lias and Upper Lias, but the Middle Lias has not yet been discovered.

In the Oolite the Taylorville fauna may possibly represent what Steinmann calls the Lower and Middle Oolite, which is about equivalent to the Inferior Oolite of England. The Upper Oolite, if it exists in America, has not yet been distinguished.

In the Malm we can distinguish at Taylorville the Callovian or Kelloway, the lowest series of the Upper Jura, and what seems to be the equivalent of the Corallian, a late stage of the Oxfordian series in Europe.

The basin of the Black hills contains the Lower Oxfordian, and in Alaska the same occurs with probably other members of the Jura, not yet distinguished. Their age appears to be in large part younger than the Callovian of Taylorville and older or only in part contemporaneous with the supposed Corallian of that locality, as previously stated by me.*

The Gold Belt series of slates is apparently in large part, if not as a whole, later in age than the rocks just referred to. It includes part of what the Russians regard as the youngest Oxfordian, and also the Portlandian or Kimmeridgian and possibly even including in part or as a whole the equivalent of their Volgian, the youngest stage of the Tithonian, the topmost series of the Jura in Europe.

In other words, it may be said that the Malm or upper Jura appears in this country to have at least four very distinct faunas, that of the Bicknell sandstone at Taylorville, that of the Black hills and Alaska, that of the Hinchman tuff at Taylorville, and that of the Mariposa and Colfax regions in California. The latter can be subdivided, as has been done above, according to the Russian classification, into several minor faunas, but as a whole they are obviously younger than the fauna of the Bicknell sandstone which I have compared with the Kelloway or Callovian.

It is not practicable to tabulate these views without giving to them an appearance of greater precision than they deserve, but nevertheless I have attempted to do this in order to put them more clearly before the minds of paleontologists.

I desire again, in this connection, to say that the subdivision of the Gold belt slates rests on very slender information and is merely suggestive. I am especially doubtful with regard to the relative age of the Colfax slates, and whether they are really the youngest or the oldest of the Gold Belt series may be considered as unsettled. In fact, I put them in the table in their present definite shape more to excite the attention and interest of collectors in this field than for any other purpose.

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* Jura and Trias at Taylorville, p. 410.

| | Lower Jura. | | Middle Jura. | | Upper Jura. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Lower Lias. | Upper Lias. | Inferior Oolite. | Upper Oolite. | Callovian or Kelloway. | Oxfordian or Oxford. | Corallian. | Kimmeridgian or Kimmeridge. | Tithonian. |
| Inyo county, California | * | | | | | | | | |
| Esmeralda county, Nevada | * | | | | | | | | |
| S. W. part, Star Peak range, Nevada. | * | | | | | | | | |
| Esmeralda county, Nevada | | * | | | | | | | |
| Taylorville, California | | * | | | | | | | |
| Beaver creek, Oregon | | * | | | | | | | |
| Taylorville, California | | | * | | | | | | |
| Canyon of the Yellowstone | | | * | | | | | | |
| Taylorville, California | | | | | * | | | | |
| Black hills, Dakota | | | | | | * | | | |
| Red Buttes, North Platte | | | | | | * | | | |
| Aurora, Wyoming | | | | | | * | | | |
| Taylorville, California | | | | | | | * | | |
| Mariposa basin | | | | | | * | | | |
| " " | | | | | | | | * | |
| " " | | | | | | | | | * |
| Colfax basin | | | | | | | | | * |

## Relative Age of the Rocks of different Localities.

In order to place the relative age of the rocks in different localities in what I regard provisionally as their correct order, I have prepared the following tabulated view of the Trias and Jura:

### Trias.

Aspen mountains, Idaho, near Soda springs. — Werfener beds of Europe (Buntersandstein).

Star Peak range (northern part)
New pass, Desatoya mountains, Nevada
Esmeralda county, Nevada — Muschelkalk.

Taylorville, California — Noric and Karnic.

American canyon, California:

*Monotis* bed.

### TRIAS OR LIAS.

American and Sailors canyons, California:

*Daonella* bed.
*Ammonites* bed.
*Gryphæa* bed.
Snow Mountain bed.

### JURA.

*Lower Jura or Liassian.*

| | |
|---|---|
| Inyo county, California.<br>Esmeralda county, Nevada<br>Southwestern part of Star Peak range (?), Nevada | Lower Lias. |
| Esmeralda county, Nevada<br>Taylorville, California.<br>Beaver creek, Oregon. | Hardgrave sandstone, Upper Lias. |

*Middle Jura or Oolite.*

| | |
|---|---|
| Taylorville { Thompson limestone. / Mormon sandstone.<br>Canyon of the Yellowstone. | Inferior Oolite. |

*Upper Jura or Malm.*

| | |
|---|---|
| Taylorville (Bicknell sandstone, Callovian).<br>Black hills, Dakota.<br>Red buttes, North Platte<br>Aurora, Wyoming. | Lower Oxfordian. |
| Taylorville, Hinchman tuff, Corallian | Upper Oxfordian. |
| Mariposa basin, zone of *Cardioceras dubium* (?)<br>Mariposa basin, zone of *Perisphinctes virgulatisformis* (?).<br>Mariposa basin, zone of *Aucella erringtoni* var. *arcuata* (?)<br>Colfax basin, with *Belemnites* and *Perisphinctes colfaxi* and *mühlbachi* | Includes from Upper Oxfordian to the Tithonian. |

## DESCRIPTIONS.

### *FOSSILS OF AMERICAN AND SAILORS CANYONS, CALIFORNIA.*

#### AMMONITINÆ.

These fossils,* although abundant and sufficiently well preserved otherwise, show no suture lines, and it is therefore not considered advisable to describe them at present.

* The specimens were collected by Dr Curtice, of the United States Geological Survey, in July 1891, in shale beds of the American canyon, north side, about one-third of a mile east of American Granite ledge, in a ravine. They were described by Dr Curtice as lying just beyond the Carboniferous in going up American canyon and before arriving at New York canyon, in what he has called the Monotis shales.

## PELECYPODA.

*Monotis semiplicata*, n. s.
Loc., American canyon.

This shell has a more elongated form than *Monotis subcircluaris*, being narrow anteriorly and then widening out posteriorly. There are concentric lines over the whole valve, but only the umbonal ridges and posterior parts of the valves are adorned by radiating ridges. These consist of coarse, linear, straight ridges or costæ widely separated and with finer lines between them. The extreme border of the posterior part of the shell in the vicinity of the hinge is also destitute of radial lines. There is a distinct but very small posterior wing, and the anterior edge has also a very slight extension, just enough to make it appear straight. The anterior or oral region is short, the umbo varying from nearly terminal to about one-fifth of the antero-posterior diameter from the oral end. The posterior end is much broader, the shape being an extended oval, narrower anteriorly than posteriorly. The umbo is situated nearer the center in young specimens, but always well toward the anterior end, and the shape of the valve does not change materially with growth. The species is gregarious, thickly crowded on the slabs, having had similar habits in this respect with *Monotis salinaria* and *subcircularis*. It is obviously either a Triassic or Rhetic species.

*Monotis symmetrica*, n. s.
Loc., American canyon.

The shells of this species, although found at the same locality in the canyon, differ from those of *M. semiplicatus* most markedly in outline and the position of the umbones. These are almost central in young shells, and about one-third of the antero-posterior diameter distant from the anterior oral edge in adults. The shape is irregularly elliptical, the long hinge line forming the upper, flattened part of the outline. The anterior end is narrower than the posterior and the branchial edges evenly rounded and gibbous. There are regular concentric ridges and some radial folds along the umbonal ridges much slighter than in *M. semiplicata* and apparently absent in one adult and one young specimen. It is much rarer than its companion species, only seven specimens having been found on the slabs with *Monotis semiplicatus*. The aspect is that of a species of *Daonella*, but the evident affinity with *Monotis semiplicata* is vouched for by the presence of similar posterior and slight anterior wings.

30190 *Daonella* (?) *subjecta.*
Loc., Sailors canyon. Coll., Dr Curtice.

The fossils of this species are much compressed and not well preserved, but they are probably referable to the genus *Daonella.* The outline varies from an ellipse, the antero-posterior axis considerably longer than the dorso-ventral, which is evidently the normal form, to an oval, with the longest axis dorso-ventral. How much of the last is distortion due to fossilization it is impossible to say, the material being very limited. The shell is marked by coarse concentric ridges near the umbo, becoming finer outwardly, as in *Daonella* and *Monotis;* the radiating lines are coarser than in any other species of *Daonella* from Sailors canyon, with a finer line between each pair of coarse ones. The hinge line is certainly that of a *Daonella,* but I have used a query after the generic name on account of the state of preservation of the specimens on hand, only two of which are whole. The radiating lines are distributed about equally over the entire surface, but are more prominent near the centers of the valves. These fossils were regarded by Dr Curtice as lying above the Monotis shales, and this agrees with the paleontology. There were no associated species in the single small slab of black shale collected.

*Daonella böchiformis,* n. s.
30189 Loc., Sailors canyon.

This shell, as the name indicates, is a close approximation to the European *D. böchi* of Mojsisovics from the passage beds between the Muschelkalk and Noric series.* The umbones are nearer the center than in that species, the concentric ridges more linear and the radial marking more distinct and closely crowded. It, however, belongs to the primitive type of the group which approximates closely to the ancestral genus, *Posidonia.* The American species is, however, evidently more distant from *Posidonia* in the genetic series and nearer the typical, heavily striated forms of the genus than the European forms. Our species is also probably smaller as a rule than the *D. böchi.* The outline is that of a flattened ellipse, the lower edge being gibbous and the hinge line flattened, the longest dorso-ventral diameter being near the center. The young shells are radiately ridged at a comparatively early stage of growth and the Posidonian stage is not strongly marked. A fragment of this species was found associated with a species of Ammonitinæ from the Ammonites bed of Sailors canyon. These were for the most part found below the Ammonitinæ and were accompanied by a few poorly preserved Pelecypoda of several other genera.

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* Daonella and Halobia, Abh. geol. Reichsanst., vol. vii, pl. 3, f. 15.

### *Daonella*, sp. (?)

This seems to differ from *böchiformis* only in outline. The umbones are nearer the anterior end and the dorso-ventral diameter at the umbones is markedly longer than that near the posterior end.

### *Daonella cardinoides*, n. s.

The valve of this shell often has an outline like some species of *Cardinia* and the longitudinal striæ are correspondingly curved toward the anterior and posterior ends; otherwise it is similar to *D. böchiformis.* A specimen of this species was found associated with the cephalopods of the Ammonites bed of Sailors canyon, but the bulk of the specimens were found in the bed below this.

In company with the species of *Daonella* there are several specimens of other species of Pelecypoda, but none of them sufficiently well preserved to be of any value for the determination of age. Some of these last are also associated with the Ammonitinæ.

### *Hemientolium*, (?) sp. (?)
Loc., Sailors canyon.

Several impressions and molds of single valves represent what I have doubtfully referred to the genus *Hemientolium.* These are very small shells having heavy concentric folds at irregular intervals like those of an ostrean. The form is aviculoid with apparently straight hinge, as is often the case in poorly preserved specimens of *Hemientolium.* There is, however, in one specimen an appendage that appears to be an anterior wing extending dorsally beyond the hinge line, and in several others the lines of growth and the irregular aspect of the same part confirms this impression. The resemblance to *H. daytonensis* is not quite close enough to make one sure of identity and I prefer to leave both genus and species uncertain. Some of them are associated in the same slab with a fragment of *Ammonites,* showing that they came from the lower part of the Ammonite bed south of Sterretts.

### *Panopea* (?), sp. (?)
Loc., Sailors canyon.

A crushed imperfect cast of a right valve has a resemblance to the species described by Gabb as *Panopea* (?) *remondi* from Sonora,* but the beak is perhaps nearer the center. There are heavy concentric folds on this cast, but these are evidently largely due to pressure, and between

* Geol. California, Pal. I, p. 23, pl. 5.

them are the fine concentric striæ figured in Gabb's shell from the lower part of the bed south of Sterretts mine.

*Entolium*, sp. (?)
Loc., Sailors canyon.

In the same slab with the above is an imperfect cast of the interior, showing the peculiar outline and teeth and apparently the extending wings of an *Entolium*.

*Gryphæa*, sp. (?)
Loc., Sailors canyon.

A small lot of this genus was found about one-half a mile distant from the Sterretts Ammonites locality, but the species is not determinable. They are supposed to belong in the upper part of the Ammonite bed. Associated with them were the fragments and impression of an almost entire valve of a delicately striated shell, and too other species of Pelecypoda, also not determinable.

### *LOWER LIAS FOSSILS OF NEVADA.*

*Arnioceras nevadanum.*

*Ammonites nevadanus*, Gabb. Am. Jour. Conch., vol. v, 1869, pt. 6, pl. 3; fig. i, iv, pl. 16.
*Arnioceras nevadanum*, Hyatt. Gen. Ariet., p. 172.
Loc., Volcano, 30 miles S. E. of Walkers lake, Nev.

The reference of this species to the genus *Arnioceras* in my "Genesis of the Arietidæ" on account of the peculiarities shown by Gabb's figure was correct. The young have a compressed outline like that of *Arnioceras ceras*, and it otherwise quite closely resembles that species. It is, however, probably larger; at least I have not yet seen any specimens of *ceras* reaching so great a size as Gabb's specimen. The whorls of the young in Gabb's figure are considerably broader than in *ceras*.

The young during the nepionic stage are doubtless round and smooth, since in the ananeanic substage the abdomen becomes subacute, the keel appearing in the metaneanic substage, and costæ develop very rapidly in the course of one-fourth of a volution into well-defined costations and never have any tuberculations. The channels appear in the anephebic substage on the third quarter of the fifth volution.

The specimen has nearly nine whorls, and in Gabb's figure it is represented with the bottom part truncated, which is not the case in this specimen, although in other respects it agrees exactly with the figure.

*Coroniceras claytoni.*
*Ammonites nevadanum*, Gabb (pars).

This species is founded upon a specimen associated with *Arnioceras nevadanum* and labelled in the same hand, probably of Gabb's own writing, *Ammonites nevadanus*, G.

The young have in the ananeanic substage (the previous stage being covered) stout, gibbous whorls with coarse tubercles such as are often found in young of Coroniceran species. These are on the genicular angles and do not increase proportionately in size during the subsequent growth of the shell. As the whorl grows they spread internally into true costæ, which become perfected during what is probably the paraneanic substage. The history of the keel and channels cannot be given, the abdomen being covered. The adult has whorls and costæ which remind one of some specimens of *Coroniceras lyra* or *Coroniceras bisulcatum*, this American form being intermediate in its aspect between these two species.

The ribs are well defined and *lyra*-like, with similar tubercles on the geniculæ. The channels are deep, somewhat narrow and smooth, and the keel is prominent, showing well above the channel ridges on the outer whorl.

### *UPPER LIAS FOSSILS FROM THE BLUE MOUNTAINS, OREGON.**

*Pecten acutiplicatus*, Meek.
*Lima sinuata*, "
*Lima recticostata*, "
Loc., Beaver creek.

This species, one of the most characteristic forms of the Hardgrave sandstone fauna of Taylorville, is represented by four specimens. Three of them are sufficiently perfect to show the characteristics of the species, and the third is a fragment of large size.

*Pholadomya nevadana.*

*Pholadomya nevadana*, Gabb. Am. Jour. Conch., vol. v, p. 10, pl. 5, fig. 7.
" *kingi*, Meek. Ann. Rep. U. S. Geol. Surv. Ter., 1872, p. 473.
Loc., Beaver creek.

This species is identical with that mentioned in my table of Hardgrave sandstone fossils as *Pholadomya*, n. sp.,† the supposed European congener of which was the *P. ambigua*, Sow., of the Upper Lias.

* These fossils all belong to the Condon collection, as mentioned above, under the heading of "Lias in California, Nevada and Oregon."

† Trias and Jura at Taylorville, p. 402.

It is represented by three specimens. The central, or what I call the branchial, region in this shell is alone furnished with plications, leaving the pedal and anterior and the siphonal and anal regions or wings smooth. The normal number of plications is nine, specimens as a rule varying but little more or less on either side of this. The species described by Gabb* as *Pholadomya nevadana* from the neighborhood of Walkers lake, Nevada, is apparently identical with this, having the same number of central plications. The figure is slightly misleading, judging from the descriptions. The type has not been found in any of the collections examined by me.

*Pholadomya multilineata.*

*Pholadomya multilineata*, Gabb. Am. Jour. Conch., vol. v., p. 10, pl. 5, fig. 6.
Loc., Beaver creek.

This species is not closely allied to *P. nevadana* in general outline, the anterior region of the body being shorter and the umbones situated nearer the anterior ends of the valves. The posterior parts are usually more elongated and broader in their ventro-dorsal diameters. The number and size of the plications differ very much from those of Nevadana. They are finer, closer set and more numerous, covering all of the central regions of the valves, leaving only the anal or wing regions and a small part of the siphonal regions smooth, and in the anterior parts of the valves the oral region alone is smooth.

Gabb described this species from volcano near Walkers lake, Nevada, and the original has been found in the Whitney collection, Museum of Comparative Zoölogy.

*Pleuromya concentrica*, n. s.
Loc., Beaver creek (?).

A well preserved specimen occurs of this genus with plainly accented concentric ridges evenly distributed over the entire surface of the valves. The umbones are situated anteriorly low and the umbonal ridges are very gibbous. The posterior or anal hinge line is extended and almost straight. The anterior parts are very short but rounded, and the margins along the pedal and branchial regions are prominently and evenly curved outward without any sinus. This shell may be equivalent to part of *Myacites subcompressus*, Meek, but the anterior outline seems to be quite distinct.

* Am. Jour. Conch., vol. v, p. 10, pl. 5, fig. 7.

*Cardinia gibbosum* (?).

*Unicardium* (?) *gibbosum*, Meek. Pal. Cal., vol. i, pl. 8, fig. 8.
Loc., Beaver creek.

This shell has the general form and aspect of a shell of this genus, and is a close ally with a similar shell of the Mormon sandstone at Taylorville. The surface is evenly covered with rather fine concentric ridges, and the beaks are very prominent and larger, and the outline differs from Taylorville species. It may have been, when undisturbed by compression, identical with Meek's figure as quoted above.

*Rhynchonella*, sp. (?)
Loc., Beaver creek.

This shell does not closely resemble *Rhynchonella myrina* of the Hardgrave sandstone, nor any species of this genus occurring in that region. It approximates in outline to the *R. gnathophora* in part, as figured by Meek,* but differs in having three prominent, sharp costæ on the elevated central area of the pedicle valve and only five costæ on either side.

*UPPER JURA FOSSILS OF THE GOLD BELT SLATES.*

AMMONITINÆ.

30201 *Cardioceras dubium*, n. s.
Loc., Texas ranch, Calaveras county, California.

The young are imperfect, but it can be readily seen that the earliest stages were smooth for a prolonged period, as in some species of the genus *Cardioceras*, and that they differ entirely from the heavily tuberculated young of the genus *Amaltheus*.

The costæ arise rapidly and do not appear to differ materially, so far as seen on the sides, from those of later stages. This is also more consistent with the characteristics of Cardioceras than with those of Amaltheus.

The costæ on the sides and genicular ridges are numerous, linear and single. There are no lateral tubercules, but occasionally the costæ disappear on the sides just before reaching the geniculæ. The geniculæ are very prominent and tuberculated.

The whorls are compressed, with sides flattened. The venter is very narrow. The inclusion varies from about one-third the diameter of the inner to considerably less, and there may be two species, one including more involute and the other the less involute forms, but both have what

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* Paleontology of California, pl. 8, fig. 1 and 1*a*.

would be called open umbilici. The keel is prominent and deeply crenulated. It is separated from the geniculæ by narrow channels, which are not crossed by bifurcations of the costæ, as in more generalized species of this genus. The serrations of the keel appear to be separated by the channels from the costæ.

The sutures were present, and, although much distorted, it was ascertained that they had large first lateral saddles and lobes, with smaller second lateral saddles and small second lateral lobes. There are auxiliary saddles on the umbilical shoulder, and the abdominal lobe is shorter than the first lateral lobes. These sutures are decidedly cardioceran. There is in the Museum of the Mining Bureau at San Francisco a fine specimen (no. 11953) of this species collected,* also in Calaveras county, which is associated with a fragment of some species of Aucella, and one in the collection of the United States Geological Survey has a fragment of what is apparently a variety of *Aucella erringtoni* on the same slab. All its closest affines are in the Upper Jura, and the comparisons made below show that it is not a species of *Pleuroceras*, the only genus in the Lower Jura which contains similar forms.

Species of *Pleuroceras* show their derivation from such forms as *Pleuroceras hawskerense* by their coarsely costated and heavily tuberculated young whorls, but the costæ of this species are linear even in the young. The sutures of *Pleuroceras* are also decidedly Arietian, having a long, narrow abdominal lobe longer than the first lateral lobes, a pair of very large, broad first lateral saddles, and broad first lateral lobes, with second lateral lobes and saddles showing on the sides, all of these being but slightly cut into by the outlines of the minor or marginal lobes and saddles. *C. dubium* cannot, therefore, be considered a species of *Pleuroceras* of the Lower Jura.

*Cardioceras* (*Ammonites*) *beaugrandi*, sp. Sauv.† This species is similar in aspect, but has not distinct channels and has incomplete subsidiary alternate costæ between the longer ones. *Cardioceras alternans*, sp. Von Buch, is a polymorphic species as usually defined, and has flat-sided, flat-abdomened discoidal forms, and also varieties that are more involute and compressed. Most of the forms, especially of southern Europe, have bifurcated costæ, but there are some specimens of all varieties showing the late development of single costæ in adults. These correspond in their characters to the neanic stage of *Cardioceras dubium*, having similar keels, channels and outline.

* Two miles west of Motherlode, Texas ranch, six miles north of Copperopolis, one-half mile below stage road from Capperopolis to Sonora and two and a half miles west of the mouth of Angels creek. Collector, Dr C. D. Voy.

† Jour. de Conch., vol. xix, xx, p. 165, pl. 10, and also as figured by De Loriol, Mem. Soc. Phys. Geneve, vol. xxiii, pl. 2, fig. 4.

There is a close representation of the American species among Russian forms usually referred to *Cardioceras alternans*, since such representatives as the one figured by D'Orbigny* under the name of *Ammonites subcordiatus* have young with single costæ and compressed whorls like those of *Cardioceras dubium*. The specimens of *alternans* figured by Rouillier† are both distinct from that figured by D'Orbigny. That figured first on plate I has alternate and bifurcated costæ like the *alternans* of more southern localities.

It is a notable fact that in the Russian fauna *Aucella* makes its appearance in the Oxfordian in company with *Cardioceras alternans*, and one of the three species which first appears, *Aucella bronni*, is that which is considered by Lahusen to be the representative of our *Aucella erringtoni*, Meek.

30204 *Perisphhinctes virgulatiformis*, n. s.

Loc., Stanislaus river, opposite Bostwicks bar,‡ near Reynolds ferry, and also opposite to Bear creek.

*P. virgulatiformis* has the peculiar closely approximated linear costæ of a group of *Perisphinctes* which occurs only in the Upper Jura throughout western Europe. This species is not a typical discoidal form of *Perisphinctes*. The whorls are decidedly involute, the inclusion being about one-third, and although the inner whorls are discoidal until a late stage and the umbilicus is what one would term open, still the outer whorl broadens rapidly.

There are several close allies in the Upper Jura of Europe. One of these is *Ammonites virgulatus*, Quenstedt, of the Oxfordian; another and perhaps even closer form is his *Ammonites planulatus siliceus* which occurs in the Solenhofen schists. All of these differ from our species in the regularity with which the pilæ bifurcate, and probably the whorls of our species may differ somewhat in outline of a transverse section, but this cannot be ascertained on account of the compression of the specimens in hand. The sutures agree closely and show that these forms are all allied species of the same group.

*C. jeremejevi* Nikitin of the Russian fauna § is a similar form, and only every alternate costation is bifurcated, so that it comes very near to the American shell, in which the bifurcation is irregular. Some of our examples have hardly any of the costæ bifurcated; others have only a few with bifurcations, but in some specimens every alternate costæ is

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* Russia and the Ural, Murch. De Vern., etc, Pal. I, pl. 25, fig. 3.

† Bull. Soc. Nat. de Moscow, 1849, p. 362, pl. I, fig. 88, pl. M, fig. 109.

‡ Dr. Curtice describes this locality as "on trail south side of and opposite great bend of river by Reynolds ferry, road from Coppertown to Sonora."

§ Ceph. d. Gouv. Kostroma, pl. 4.

bifurcated on parts of the whorl. It seems probable that the American species had rounder whorls than *P. jeremejevi.*

103460 *Perisphinctes*, sp. (?)

Loc., Stanislaus river, opposite Bostwicks bar, near Reynolds ferry.

This is a form of *Perisphinctes* with the lateral ribs well separated, as in most species of the genus found to the west of the Sierras. The whorl is broader at the same age than in any other species mentioned in this paper; there are consequently fewer whorls at the same age. The lateral costæ are single and very long, the bifurcations occurring well up on the abdomen.

*Perisphinctes*, sp. (?)

Loc., south bank of Tuolumne river at Moffats bridge; Stanislaus river, near canyon opposite mouth of Bear creek; and six miles from Copperopolis on road to Sonora and grade to Angels creek.

There are several fragments collected by Dr Curtice at these three localities which probably represent more than one species, but there is nothing to indicate the age of the rocks farther than that they are high up in the Jurassic.

30203 *Perisphinctes filiplex* (?)

*Ammonites filiplex*, Quenstedt. Ammonites d. Schwab. Jura, vol. iii, pl. 126, fig. 3.

Loc., south bank of Tuolumne river at Moffats bridge, and Stanislaus river near canyon opposite Bear creek.

The fragments representing this form are interesting because they exhibit in a marked manner the peculiar widely separated, single lateral costæ, regularly bifurcated on the abdomen, of the group of *Perisphinctes alternans* from the Upper Jurassic of Russia which is mentioned at the end of the description of *P. colfaxi*. The fragments are, however, so closely similar to the *Ammonites filiplex* of the Solenhofen slates that I have ventured to place them provisionally under this name.

There are no tubercles on the lateral costæ in any of these specimens, nor are there any indications of affinity with species of *Olcostephanus*, although they otherwise closely simulate the gerontic (senile) whorls of some species of that genus.

The fragments of this species show that it reached a large size, and the characteristics are extremely close in the adult stage to those of the

young of *P. skidegatensis*, Whiteaves, as figured by him.* The regularity of the bifurcated costations of these fragments is different from those of *filiplex*, but these may have been interrupted by more or less single costæ on other parts of the whorl, and in that case they would be identical. One fragment showing a portion of the inner whorls was found by Dr Curtice six miles from Copperopolis, on the road to Sonora and grade to Angels creek. If, as is supposed, this be identical with the species here described, the first four whorls or thereabouts have a close resemblance to the young of *P. mühlbachi*, but the costations of the next or fifth whorl become more widely distributed and similar to those of the larger specimens described above. The increase of the dorso-ventral diameters is not so rapid as in *mühlbachi* and the sides of the whorls are not so broad, the whole shell being more discoidal.

*Perisphinctes colfaxi.*

*Ammonites colfaxi*, Gabb. Am. Jour. Conch., vol. v, pt. 1, 1869–'70, p. 7, pl. 4, fig. 2.

Loc., railroad cut one mile west of Colfax.

This important specimen, which has been lately brought to light in the collections donated to the Museum of Comparative Zoölogy by Professor J. D. Whitney, turns out to be entirely distinct from what it has been supposed to be by most authors. Gabb's figure in the American Journal of Conchology does not give the great prominence and true facies of the ribs, but does show the purely perisphinctean characteristics of these parts. The specimen has from ten to twelve whorls and is of the size of Gabb's figure. The living chamber is over one-half of a volution in length. The whorls increased very slowly by growth, the whole shell being discoidal; the inclusion is slight, covering only the abdomen. The form of the whorl in section had rounded, somewhat compressed sides and a rounded, broad abdomen. The ribs are more regular than in Gabb's figure, their irregularity in curvature being largely due to compression. The rule in the neanic stage is for each alternate rib to be bifurcated, the parts between the bifurcations being elevated and the bifurcation on the exterior of the shell was probably coarsely tuberculated or nodose. This gives the bifurcated ribs a very coarse, massive aspect. The alternating single costæ are more acute and reach entirely across the sides and abdomen. There are sometimes two or three single costæ between the bifurcated ones, and these irregularities increase on the last whorl. The bifurcations are about the middle of the side, but may

* Mesozoic Fossils, vol. ii, pt. 1, pl. 9, fig. 1.

vary from near the umbilical shoulders to the edge of the abdomen. The single costæ are sometimes, although rarely, bifurcated on the abdomen and occasionally one of the branches of a bifurcation may be itself bifurcated on the abdomen. In some rare cases, instead of a bifurcation of the single lateral costæ or of a branch of the bifurcated lateral costæ, there is a single separated costation on the abdomen lying between the bifurcated or longer single costæ.

*Perisphinctes* (*Ammonites*) *skidegatensis*, sp. Whiteaves, is an allied species of the same group, and the adults of the two may be more similar than one would suppose from the figure given by Whiteaves,* which is probably that of an aged specimen. In *skidegatensis*, however, the intermediate single costæ are confined to the abdomen, and these parts are more regular.

*Perisphinctes colfaxi* obviously belongs in the group of *Perisphinctes biplex*, sp. Sow. (?), of the Upper Jura, and its nearest affines are such species of *Perisphinctes eupalus* (?), sp. De Loriol, in "Etage Jurassique de la Haute Marne" † in the Kimmeridgian and the *biplex* described by De Loriol and Pellat in "Formations Jurassique des Environs de Boulogna-Sur-Mer" ‡ from the Portlandian. Both of these forms, which are also related to *biplex*, have similar single costæ, although there are no such marked irregularities as in this species, and the whorl was more compressed. The center of the umbilicus is exposed in *colfaxi* on the cast and also on the reverse, which shows a cast of a part of the exterior of the shell. The surface evidently did not differ very much from the cast of the interior described above, and the young was smooth for a time and very discoidal, as in the *biplex* group. It especially resembles the young of *Perisphinctes alternans*, sp. Fischer von Waldheim (Pallasianus), of the Kimmeridgian of Russia.§ The sutures of *alternans* are very close to those of this species, and the single ribs are prevalent, according to De Verneuil, and the form is more like that of *colfaxi* than of any other European form. This entirely accords with my first impression, that the nearest affines of this species existed in the fauna of the Upper Jura of Russia. The same is also true of *skidegatensis*, the young of which, as figured by Whiteaves, appears to be almost identical with specimens of *alternans* (in the Museum of Comparative Zoölogy) from Russia, which do not have single ribs.

Gabb knew that this fossil was probably Jurassic, but was in error in supposing that it indicated the presence of the Lias near Colfax.

* Geol. Survey of Canada, Mesozoic Fossils, vol. i, pt. i, pl. 7.

† Mem. Soc. Lin. de Norm., xvi.

‡ Mem. Soc. Phys. et D'Hist. Nat. de Geneve, xxiii.

§ De Verneuil: Russia and the Ural Mts., p. 427, pl. 32, figs. 1–3, and Orytogr. du Gouv. Mos.

*Perisphinctes mühlbachi*, n. s.

Loc., near Greenwood, El Dorado county, California.

The young are discoidal, but the increase in dorso-ventral diameters is by no means so slow as in the normal forms of *Perisphinctes*. In the large specimen which served as type of this description there were about seven whorls, as estimated, in a diameter for the whole shell of about 125 millimeters.

The lateral costæ are single, much coarser than in *P. virgulatiformis* and very closely set. There were about forty-seven on the seventh whorl and as many on the sixth. This gives the costæ a more crowded aspect on the inner whorls than on the outer one, the costations being wider apart proportionately in the older stages than in the younger whorls. The lateral costæ are slightly arched forward, single, sharply defined and prominent. The bifurcations are regular and set well upon the abdomen, so that they are concealed, as in most of the species described in this paper, by the involution of the whorls. The absence of straight, unbifurcated costæ is noticeable in this species and *P. filiplex* (?), but the latter has fewer costæ and the bifurcations are not wholly hidden by the involution of the whorls.

The Whitney collection in Museum of Comparative Zoölogy contains a water-worn specimen of this species without locality. The matrix indicates, however, the same bed and it may be considered as Eldorado county. A specimen collected by Dr Curtice on wagon road two miles west of Reynolds ferry and one mile west of the motherlode in Tuolumne county, California, is certainly very closely related to this species, but the condition of the specimen does not permit a more positive opinion.

There are two specimens of *mühlbachi* in the Museum of the Mining Bureau at San Francisco. Number 9020 is said to have come from Sailors canyon. The matrix, however, is like that of the specimen from near Greenwood, and Dr Curtice, having examined these examples, considers the locality to be doubtful. They are probably from the same bed as the typical specimen. The costæ on the outer (sixth ?) whorl of the largest specimen of these are more numerous apparently than in the typical specimen, and in extreme old age the costæ are single.

No specimen has yet been recorded as having been found in place, but the dark colored slate in which all specimens occur buried is identical lithologically with that containing Belemnites from American canyon near Greenwood, and the type specimen was picked up somewhere in that vicinity. That it was not identical with *P. skidegatensis*, Whiteaves, is evident from this description, that species having bifurcated costæ with incomplete, single abdominal costæ between them.

The type of this species was obtained by Mr Lindgren from Mr John Mühlbach of Greenwood.

*Olcostephanus lindgreni*, n. s.
Loc., near Colfax, Placer county, California.

The specimen representing this species is unluckily so much altered by compression that some of its characteristics become doubtful. The tubercular aspect of certain of the lateral costæ is probably due to flexures, occasioned by pressure in the direction of the dorso-ventral diameters of the whorl. The lateral costæ are divided upon the sides into numerous smaller costæ, which cross the abdomen continuously; that is to say, the costæ have the aspect of a species of *Olcostephanus* of the Virgatus group of that genus, which has been so finely described by Michalski * in the Russian fauna of the Upper Jura. So much depends upon the development of the young in this genus that I cannot compare it with any species yet described. That it is not probably identical with the adult stage of any one described by Michalski seems to be plain even in this imperfect specimen.

*Œcotraustes denticulata*, n. s.
Loc., Stanislaus river, Bostwicks bar, near Reynolds ferry.

This is a species belonging to the smooth-whorled, denticulated section of the genus which occurs in the Upper Jura. The specimens, although only fragments considerably compressed, show the denticulations, the aperture in part and the sutures. The characteristics of all of these indicate plainly that it is a species of *Œcotraustes*, allied to such forms as *Œcotraustes* (*Ammonites*) *lochensis*, sp. Oppel., of the Oxfordian. It may be that its nearest congener is in the Solenhofen slates, but in order to make such a close diagnosis better specimens must be procured.†

The sutures have a short abdominal lobe, with large siphonal saddles, large first lateral lobes, with three long, slender terminal lobes and other parts of the outline, as in the section of the genus to which it is referred. This genus is sometimes confused with *Amaltheus* of the Lower Jura, but the resemblances are very slight and do not need discussion.

## BELEMNOIDS.

*Belemnites pacificus.*

*Belemnites pacificus*, Gabb. Proc. Cal. Acad. Sci., 1864, p. 173; Geol. Cal., vol. i, p. 482.

Loc., Mariposa county and American canyon near Greenwood, California

In the remarks below on this species I have joined what I really think are four species; one short one from Mariposa county, the true

* Die Ammoniten d. unt. Wolga-stufe.

† A compressed fragment of a specimen from Texas ranch, Calaveras county, now in collection of the National Museum at Washington, is apparently a species of *Œcotraustes* and may be identical with this, but the condition of the specimen did not permit exact comparison.

*B. pacificus;* one with an extremely long guard from Greenwood. There is no data, however, for determining the length of the guard in the true *pacificus.* The third, if distinct, ought to be a much stouter and larger species than either of these, and is found in the black slates of Greenwood. The fourth form, having a small pencil-like guard, is found in the light-colored slates near Greenwood.

The specimens of *Belemnites pacificus* from Spanish Flat in the collection of the University of California are exceedingly poor and agree in this respect with the description given by Gabb.* In the same collection there are three alveoli labelled from Mariposa estate. The labels are the same handwriting, probably Gabb's, and gummed to the specimens, which are obviously the types.

The specimen from the first ravine west of Hell's hollow, Mariposa county, agree in black color of slates and in the narrowness of the alveoli. A specimen from near Pine Tree lode is evidently a better preserved cast of same. These localities are referred to by Professor Whitney as being the places at which Belemnites had been found in a note to appendix B of Geology of California, volume i. There is also a larger cast of an alveolus labelled from Oregon bar, El Dorado county, in a lighter colored slate and 23 millimeters in the greatest diameter, and, as estimated, not over 10 millimeters in the shortest diameter.

There are two species of *Belemnites* occurring near Reynolds ferry, opposite Bostwicks bar, Calaveras county. One is narrow and cylindrical and may be identical with the similar form from Greenwood, El Dorado county; the other is of the usual shape of *B. pacificus,* considerably stouter and very likely shorter in proportion. All are fragments in a poor state of preservation and the species are not identifiable. In the dark slates at Stanislaus river, opposite Bear creek, and at the locality six miles from Copperopolis and grade to Angels creek, there is a long cylindrical form which may be the same species as the similar form found near Reynolds ferry, but one cannot be sure beyond the general fact of similarity.

Dr. Curtice, collecting for the United States Geological Survey, found *Belemnites* evidently very similar, if not identical species, in the black slates of the American canyon near Greenwood. These remains are not rare, but specimens well enough preserved to be of any use are very rare. In the light-colored slates of the same gulch and immediately above the black slates a fossil was found which is probably the young of this same species or a close ally. The alveolus in part was preserved, but both it and the pencil-like rounded cast of the guard looked quite distinct from the elliptical form of a section of *B. pacificus.*

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* Proc. Cal. Acad. Sci., Nov 17, 1864., p. 173.

The longest specimen collected by Curtice measured 16 centimeters, and when complete was about 20 to 22 centimeters; the diameter at about one-half the length of the alveolus was estimated on account of the position of the cast in the rock, and this was between 13 and 15 millimeters in its longest diameter, and, as actually measured, 10 millimeters in the shortest diameters. At the distance of 16 centimeters the guard was about 7 millimeters in longest diameter.

The alveoli are mere casts of the free ends of the shells, but they are universally short, rapidly tapering and much compressed. The largest specimen collected by Dr Curtice was 17 millimeters in diameter near the end of the compressed alveolus. This was a rotund ellipse, and probably this was the real form of the guard.

The writer visited the locality in company with Dr Curtice during the summer of 1892. The fossilization of these *Belemnites* is very peculiar, and in imperfect specimens, of which there are considerable numbers, very misleading. The casts of the guards are divided by irregular septa of oxide of iron, giving the ordinary imperfect hollow moulds the aspect of a plant fossil or a very poorly preserved Orthoceratite with distorted septa. This is probably due to the movement of the rocks, which fractured the straight guards and allowed the water to penetrate the fissure and deposit a layer of iron; then when the shell was wholly dissolved the hollow cast presented the aspect of a tube divided by irregular septa of oxide of iron. Long cylindrical fossils found at Chili bar, also in black slates, exhibited more or less regular cracks of this kind not unlike the sutures of *Orthoceratites*, and are probably fossils of this species of *Belemnites*.

## PELECYPODA.

### *Avicula*, sp. (?)

Loc., Stanislaus river, as above.

The most perfect specimens closely resemble the so-called *Aucella impressæ*, Quenstedt, from the Upper Jura, but this shell has a small *Aucella*-like ear in the right valve, and I could not tell whether what I saw in this specimen is a similar ear or a tooth. Quenstedt's shell is, as pointed out by Lahusen, not a true *Aucella*. I have referred this species for the present to *Avicula*, because there are characteristics in both directions.

There are fragments of several species of bivalves and of Pectens from the strata of Stanislaus River locality that would be very useful if more perfect.

Associated with these there is a *Turbo* (?) and a species of *Cerithium*, which are not of much value for the definition of the age of the rocks in which they occur.

*Amusium aurarium*, Meek. 103459

Loc., six miles from Copperopolis on road to Sonora and grade to Angels creek.

A shell probably of this species occurs at this locality, but it is not perfectly symmetrical, as in Meek's figure of the same species.

*Aucella erringtoni*, Meek.
Variety, *arcuata*.

*Aucella erringtoni*. Geol. Sur. Cal., vol. I, appendix, pls. 1, 2*a* (not figs. 3, 4, 5).

Loc., south bank of Tuolumne river at Moffat's bridge; Stanislaus river near canyon opposite Bear creek, and six miles from Copperopolis on road to Sonora and grade to Angels creek.

This variety represents the extreme form and is arcuate in the left valve with a very prominent umbo. The striations are less decided than in *Aucella elongata*. There are a few shells which are apparently smooth, while most are striated as in *Aucella elongata*. The task of separating this from other varieties by the characteristics of the relative proportions of the left valve to the right and other characters, such as the relative prominence of the umbones in both valves, shape of the hinge line in the right valve, and so on, is impracticable on account of the compressed and more or less distorted condition of every fossil. It is, obviously a near affine of *Aucella pallasi*, sp. Keyserling,* as figured and described by Lahusen from the zone of *Cardioceras alternans* in Russia, in so far as the general shape and striations are concerned, and Keyserling's original drawings and descriptions of *Aucella pallasi* give longitudinal striations and a form of shell so close to this that without the right valve and hinge line they would be considered identical. With the complete information given by the drawings of the latter, however, it becomes apparent that they are not both referable to the same species. The hinge line of the right valve of the *arcuata* is more like that of *mosquensis*, while the general shape of the shell alone is like that of *pallasi mosquensis*, from the Volgian or middle part of the Upper Jura in Russia.

*Aucella concentrica*, Fischer,* has a right valve and general outline closely similar and possibly identical with *arcuata*. The left valve, although not completely shown, appears to be similar to that. The same species and the stout, rotund variety shown in figure 6 has its counterparts in some specimens from the last locality given above which have no striæ. The outline of the hinge of the right valve need only be com-

* Reise in Petsehoraland, pl. 16.

pared with the *A. concentrica* as figured by Keyserling to see that they are not similar, the *concentrica* of Fischer having a right umbo short and rounded. Fischer's specimen came from Amackshak bay, near Souktrum, Alaska.

Typical examples of this species also occur on left bank of Merced river one-quarter of a mile below Bentons mills, Mariposa county, California, where they were collected by Dr White and others.

The narrow form of *Aucella piochii*, Gabb, from Riddles, Oregon,† resembles this species closely enough in its form to be considered identical, but it has no radial striæ. I compared this last with all the Gold belt Aucellæ in turn and independently before arriving at *A. erringtoni*, var. *arcuata*, and found it agreed with them all to exactly the same degree as *arcuata*, and, finally, that, like *arcuata*, it was easily referred to *Mosquensis* by its right valve, and that that species and not *pallasi* was its nearest foreign representative, in spite of the resemblances of the left valves. The explanation of this fact is that *pallasi*-like forms, being simply narrow shells, as contrasted with broad ones, may occur in varieties of any species of *Aucella*, and the test that such resemblances are not a matter of genetic affinity, but of simple morphic equivalence, lies in the characteristics of the least modified part of the shell, the right valve.

### *Aucella elongata*, n. s.

*Aucella erringtoni*, Meek. Geol. Cal., vol. i, appendix, pl. i, figs. 5–5*e* (not figs. 1–4).

Loc., Stanislaus river opposite Bostwicks bar.

This species has an excessively elongated shell, but the outline of umbonal ridge is apparently straight or only very slightly curved. The shell is heavily striated in all specimens, the striations being generally distributed. The striæ being much lighter, and therefore easily obliterated by pressure on the extreme anterior and posterior areas, they may be absent upon either or both of these in large specimens. This accounts for the discrepancy in the descriptions of Meek and Gabb, one finding them more strongly developed on the anterior and the other on the posterior region, but they are apparently, as stated by Meek, usually lighter on the posterior region. It is to be noted, however, that none of the specimens here described have such bare posterior regions as some of those figured by Meek. They are all more similar to his figure 5 than to 5 *a–e*. The hinge line of the right valve rounds out anteriorly more than in *Aucella erringtoni*, var. *arcuata;* the oral region is more protuberant.

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* Pinart: Voyage a la côte Nord-ouest de l'Amer., pl. A.

† Paleontology of California, vol. i, pl. 25, fig. 173 (not vol. ii, pl. 32).

The wing is of about the same size, but it is straight. The posterior wing is broader and more distinctly marked than is usual in var. *arcuata* in both valves, and especially long and prominent in the left valve. The umbo is apparently less prominent in the left valve than in *arcuata*, and that of the right valve is possibly less acute, but these characters are rendered somewhat doubtful by the compressed condition of the fossils.

It is obvious, as stated by Lahusen, that this is the representative form of *Aucella bronni*. That species has the umbo of the left valve less prominent than in most species of the same genus, and the shape of the hinge area and umbo of the right valve is very similar to that of this species. It is from the zone of *Cardioceras alternans* in the Oxfordian of Russia, and is regarded by him as one of the oldest and most primitive of the Aucellæ.

This fact is extremely interesting in connection with the supposed age of the rocks of the locality given above, which also contains the *Cardioceras dubium*, a representative of *Cardioceras alternans*, and also because of the following additional observations of Lahusen. This author quotes his *Aucella bronni* as associated with *Oppelia tenuilobata*, Oppel, in the Polish Jura, and also regards the *A. mosquensis*, Tullberg, from Nova Zembla as identical with *bronni*, and says that it occurs with *Cordioceras alternans*, and also that the Spitzbergen species is found in the same association as in Russia. This form also occurs at Texas ranch, Calaveras county, California, and with it a variety still more like *Posidonia*, the outlines less elongated, which I have labelled var. *posidoniformis*.

Var. $\dfrac{\textit{elongata}}{\textit{aviculæformis}}$.

*Aucella erringtoni*, Meek. Geol Cal., vol. I, appendix, pl. 1, fig 3 (not figs. 1, 2, or 4, 5).

Found only at locality 719, Texas ranch, Calaveras county (Meek's locality was Mariposa county).

This variety is just intermediate between *elongata* and *aviculæformis*, and differs from the latter only in having a narrow posterior wing. The outline given by Meek is an extreme form of this variety, in which the dorso-ventral diameter is much shorter in proportion to the antero-posterior diameter than in the normal forms.

Var. *Elongata orbicularis.*

This differs merely in being more circular in outline and approximates toward *Aucella orbicularis.*

*Aucella aviculæformis.*

Loc., near Reynolds ferry, south bank of Tuolumne river, six miles from Copperopolis.

This has an outline similar to that of some species of the genus *Avicula.* The young are similar to *Aucella orbicularis*, but become more elongated in adults without, however, entirely losing the orbicular form. The posterior wing is large and the posterior outline like that of an *Avicula* in some specimens; in others it is similar to *Posidonia.* The oral region is very protuberant and more rounded than that of var. *elongata*, but does not project so far anteriorly, especially in the right valve, as does the same region in *orbicularis.* The hinge region is broad and straight, the valve in outline being similar to the right valve of *orbicularis;* but the diameter from the umbo to the border of the dorso-ventral edge is longer in proportion to the antero-posterior or transverse diameter. In fact it is just intermediate between *elongata* and *orbicularis* in many characters, but differs from both by its peculiar form and outline. The striæ are persistent and about the same as in *elongata* and *orbicularis.* There is nothing similar in European faunas, so far as I know. This species has the general aspect of *Aucella crassicollis*, var. *solida*, but differs in the development of the posterior wing and striations. Eichwald's figures of *Aucella pallasi*, figures 3 and 4, and *Aucella mosquensis*, figures 13 and 14* (no other figures in this plate), resemble this variety closely, but have smooth shells and the posterior wing is not developed. The *Aucella mosquensis*, Whiteaves,† is considered by Lahusen ‡ as very similar to his *Aucella volgensis*, but he has not been able to identify the two. He also makes a comparison between his *Aucella mosquensis* and the Cretacic *Monotis concentrica* of Salta, but is not able to identify them. *Aucella mosquensis* is not similar to *Aviculæformis*, but Volgensis of Lahusen is certainly a representative form in Europe, although in this, as in the other species of European faunas, the development of the posterior wing and absence of radiating striæ are marked differences.

Var. *acuta.*

Loc., six miles from Copperopolis.

This may be merely a noteworthy form of *aviculæformis*, or it may indicate another series between *elongata* and *aviculæformis.* I think it is simply an extreme form of *aviculæformis*, having, however, a subacute angle in the lines of growth on the umbonal ridge and a correspondingly subacute outline at the posterior extremity.

* Mangischalk et Aleutian Inseln., pl. 17.

† Mesozoic Fossils, vol. i, pt. i, pl. 10.

‡ Lahusen, Russichen Aucellen Mem. Com. Geol. St. Petersburg, viii, No. 1.

*Aucella orbicularis.*

*Aucella erringtoni*, Meek. Geol. Cal., vol. II, appendix no. 1, fig. 4 (not figs. 1–3 or 5).



Loc., in Calaveras county, generally.

This variety, as the name indicates, has a remarkably circular outline, and the oral region is exceedingly gibbous and projects anteriorly as in Meek's figure; but his figure is certainly an extreme form, resembling, except in size, the young shells of the specimens from which this description is taken. All the good specimens examined by me are also right valves, so that it is quite possible that Meek's extraordinary form may be another variety, if not a distinct species. Right valves of this variety can be easily mistaken for slightly distorted specimens of *Amusium aurarium* in which the anterior wing has been lost, so closely do they approximate in outline to Meek's figure of that form, and the shell also, though usually marked by prominent lines of growth and striæ, is sometimes quite smooth.

The unequal umbo having the characteristic anterior reëntrant curve and wing of *Aucella* is, however, usually sufficiently well marked to prevent an observer from making this mistake. This variety is certainly very similar to the *Aucella crassicollis*, var. *solida* in the shape of the younger part of the right valve, but differs materially in having striations and in the shape of the adult.

One specimen, the right valve of a young shell of this variety (or at least at present here included), has exactly the outline of Eichwald's *Aucella concentrica** in the extreme variety, as given in his figure 2, showing that a corresponding variety occurs in Alaska in this species. Nevertheless, Eichwald's figure shows a smooth shell, whereas the valve of the California species is strongly striated over the entire surface. Usually, however, *orbicularis* approximates in the shape of the right valve to Eichwald's figures 5 and 6 of *Aucella pallasi.* The anterior curve of oral and hinge region is not so protuberant and does not project dorsally, and the valves are usually striated, left valve being entirely distinct.

It is evident that this species, *aviculæformis* and *elongata*, belong to the *pallasi* type, having broad hinge line and rotund oral areas in the right valves, whereas *arcuata* belongs to the narrow hinged type of *A. mosquensis*, the umbo also being more nearly central in right valve than in the former.

* Mangischalk et Aleutian Inseln, pl. 17.

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# THE SHASTA-CHICO SERIES*

BY J. S. DILLER AND T. W. STANTON

*(Read before the Society December 27, 1893)*

CONTENTS



## HISTORICAL REVIEW.

Of all the formations on the Pacific coast none have received greater attention than those which belong to the Cretaceous. The earliest ex-

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tensive investigations in this field are published in the reports of the California Geological Survey, under the direction of Professor Whitney. Mr Gabb, of that survey, recognized four horizons in the Cretaceous, and the names given them by him are noted in the first column of the accompanying table. The Téjon,* Martinez and Chico were considered to belong to the Upper Cretaceous. All the Cretaceous below the Chico, composed of the beds exposed at Horsetown, on the north fork of Cottonwood creek, in Shasta county, and at a number of points in the Coast range, was grouped together under the name Shasta.

| | Gabb,† in California. | White,‡ in California. | Diller and Stanton,§ northern California and Oregon. |
|---|---|---|---|
| Eocene. . . . . . . . . . . | . . . . . . . . . . . . . . . . . . | . . . . . . . . . . . . . . . . . . | Téjon. |
| Upper Cretaceous. . | Téjon . . . . . . . . . . . .<br>Martinez.<br>Chico. | Chico-Téjon. . . . . . . . | (Hiatus and unconformity.) |
| | | Probable place of the Wallala formation. | Shasta-Chico Series. { Chico. |
| | | (Hiatus of White. Unconformity of Becker.) | Horsetown. |
| Lower Cretaceous. . | Shasta. . . . . . . . . . . | Shasta. { Horsetown. . . . .<br>Knoxville (including Mariposa). | Knoxville. |
| Jurassic. . . . . . . . . . . | Mariposa . . . . . . . . | . . . . . . . . . . . . . . . . . . | Mariposa. ‖ |

The investigations of Conrad, Jules Marcou and Heilprin have shown that the Téjon, instead of being Cretaceous, belongs to the Eocene.¶

In connection with the investigations of the United States Geological Survey, with special reference to the quicksilver deposits of the Pacific

* The proper pronunciation of this Spanish word is "tahone."

† Geol. Survey of California, Paleontology, vol. ii, preface by Whitney, p. xiii.

‡ U. S. Geol. Survey, Bulletin no. 82, pp. 184 and 241.

§ Bull. Geol. Soc. Am., vol. 4, pp. 205-224 and 245-256.

‖ Hyatt: Bull. Geol. Soc. Am., vol. 5, pp. 395-434; see also Smith: Ibid., pp. 243-258.

* For a more complete reference to the literature of the Cretaceous of the Pacific coast, see U. S. Geol. Survey, Bulletin no. 82, by Dr C. A. White, and Bull. Geol. Soc. Am., vol. 4, pp. 245-249, by T. W. Stanton.

coast and to the Gold belt of the Sierra Nevada, the studies of Dr White* and Dr Becker† resulted in changing the grouping of the Cretàceous sediments. They recognized both the Téjon and the Chico, but they considered them as belonging to the same continuous series of beds, the upper or Téjon portion belonging to the Eocene, the Chico to the Cretaceous. They gave the joint name Chico-Téjon to this set of beds, as indicated in the second column of the table.

Dr Becker discovered near Wallala, on the coast some miles north of San Francisco, a series of interesting fossils containing forms which had not been previously recognized. The beds in which they were found he called the Wallala beds. Dr White described the fossils, of which the most characteristic is *Coralliochama orcutti*, and concluded, from paleontologic grounds alone, that these beds belong immediately beneath the Chico. According to Dr Becker they rest unconformably upon the metamorphic rocks.

The beds exposed at Horsetown and elsewhere in Shasta county they called the Horsetown beds, while others, in which the characteristic fossil is of the genus *Aucella* and well exposed near Knoxville, in Napa county, they called the Knoxville beds. At first, although the Knoxville was recognized by paleontologic evidence as being older than the Horsetown beds, it was supposed that there was a considerable interval of time between their periods of deposition. Owing to the investigations of Dr Becker at Riddles, in Oregon, as well as those of Mr Diller at the same place and in Shasta and Tehama counties, California, it was shown ‡ that these two sets of beds were more closely related than had been previously supposed, so that in his correlation bulletin § of the Cretaceous formations of the United States Dr White suggests that their successive deposition took place without a time interval.

During the last ten years the writers have had an excellent opportunity to study the Cretaceous of the Pacific coast, especially in northern California and Oregon, and also to some extent in the state of Washington. The results are expressed in the fourth column of the accompanying table.

In Oregon the Téjon is entirely distinct from the Chico. It rests with a marked unconformity on the Cretaceous of that region, and is separated from it by a time interval during which there was considerable erosion. In northern California the Téjon is absent, but in middle and southern California it is well represented, and, according to many observers, is conformable with the Chico.

It has recently been shown by Mr Gilbert D. Harris ‖ that the Téjon

* U. S. Geol. Survey, Bulletins nos. 15, 22 and 82.
† Ibid., Monograph XIII and Bulletin no. 19.
‡ Bull. Geol. Soc. Am., vol. 2, pp. 201–208.
§ U. S. Geological Survey, Bulletin no. 82, p. 184.
‖ Science, vol. 22, p. 97, August 18, 1893.

fauna at its typical localities may be correlated with the lower Claiborne fauna of the Gulf states. This is not the oldest Eocene fauna, as it occurs in Alabama about 1,200 feet above the base of the Eocene. On the other hand, the Chico fauna as typically developed in the Sacramento valley does not indicate the latest Cretaceous time, so that a considerable time interval is suggested by the paleontologic evidence. The evidence of the reported commingling of the Chico and Téjon faunas has been obtained in the neighborhood of mount Diablo and northward, where the strata are much dislocated and folded and the true stratigraphic succession often obscured.

The Chico, Horsetown and Knoxville beds have been found to grade into one another in such a way as to show that they are simply different phases of one continuous series of deposits extending without an important interruption of any kind from the bottom of the Knoxville to the top of the Chico. For this set of beds the term Shasta-Chico series has been proposed.*

## Sections of the Series.

### *ELDER CREEK SECTION.*

The thickest section of this series that has yet been measured, and in fact the thickest section yet known, is well exposed on Elder creek, in Tehama county, California, where the Knoxville beds have an apparent thickness of 20,000 feet, the Horsetown beds approximately 6,000 feet, and the Chico beds 4,000 feet, so that the total thickness of the Cretaceous section in that region appears to be 30,000 feet.†

In the accompanying table the section is given in some detail, including the fossils which occur at different horizons.‡

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* Bull. Geol. Soc. Am., vol. 4, pp. 205–224, and 245–256. Since the papers referred to were written we have spent several months in the field, completely reviewing the Cretaceous of northern California. The results fully confirm our previous views.

† This enormous thickness seems incredible, and yet, after going over the section several times, we have not been able to find reliable evidence for its reduction. No duplication of strata could be recognized either upon lithologic or paleontologic grounds, but, on the contrary, there seems to be a regular succession without repetition in both rocks and fossils from top to bottom. The evidence, however, is not strong, for in the Knoxville beds, which comprise the greater portion of the series, there are few if any distinct lithologic horizons by which repetition could be certainly recognized, and very few fossils were found in them along the line of the section. Small folds and faults, both normal and thrust, were observed so related to the dip of the strata as in some cases to increase and in others diminish the thickness of the section. The effect of the one, as nearly as could be estimated, counterbalanced the other. It is important to note in this connection that the complete series of Shasta-Chico beds is not exposed in this section. At the eastern end of the section the Chico beds disappear unconformably beneath the later deposits of the Sacramento valley, which covers its topmost layers. The western end of the section is terminated by serpentine which is probably of later eruption.

‡ This section was measured in 1889 by J. S. Diller and J. Stanley-Brown. Am. Jour Sci., vol. xl, p. 476.

| | Feet. | Rocks. | Fossils. | |
|---|---|---|---|---|
| Chico beds. | 500<br>1,000 | Shales with some thin sandstones. | *Inoceramus.*<br>*Pecten*, sp. a. | |
| | | Sandstones. | *Amm.* (*Pachydiscus*) *newberryanus.*<br>*Inoceramus whitneyi.* | |
| | 1,500<br>2,000 | Shales containing one 25-foot bed of sandstone. | | |
| | | Massive sandstone. | *Thetis annulata.*<br>*Chione varians.*<br>*Tellina ashburneri.*<br>*Tellina parilis.*<br>*Gyrodes expansa.*<br>*Anchura californica.* | |
| | 2,500 | Conglomerate. | | |
| | | Massive sandstone with thin conglomerate. | | *Pecten operculiformis.*<br>*Exogyra parasitica.*<br>*Cucullæa truncata.*<br>*Trigonia leana.*<br>*Trigonia evansana.*<br>*Meekia sella.*<br>*Coralliochama orcutti.*<br>*Chione varians.*<br>*Caryatis nitida.*<br>*Thetis annulata.*<br>*Dentalium stramineum.*<br>*Lunatia avellana.*<br>*Gyrodes expansa.*<br>*Anchura californica.*<br>*Anchura falciformis.*<br>*Cinulia matthewsoni.*<br>*Actæon inornatus.* |
| | 3,000 | Shales. | *Pecten operculiformis.*<br>*Cucullæa truncata.*<br>*Nemodon vancouverensis.*<br>*Trigonia evansana.*<br>*Trigonia leana.*<br>*Trigonia æquicostata* (?)<br>*Pectunculus veatchi.*<br>*Meekia sella.*<br>*Chione varians.*<br>*Caryatis nitida.*<br>*Coralliochama orcutti.*<br>*Dentalium stramineum.*<br>*Lunatia avellana.*<br>*Anchura californica.*<br>*Amm.* (*Desmoceras*), sp. a. | |
| | | Conglomerate with limestone pebbles. | | |
| | 3,500 | Sandstone, shale and conglomerate. | | |
| | | Chiefly conglomerate. | | |
| Horsetown beds. | 4,000 | Shales with thin sandstones. | | |
| | 4,500 | Shales. | | |
| | 5,000 | Sandstone. | | |
| | | Shales. | | |
| | 5,500 | Shales. | *Pecten operculiformis.*<br>*Nemodon vancouverensis.* | |
| | 6,000<br>6,500 | Shales. | | |
| | 7,000<br>7,500<br>8,000<br>8,500 | Shales and thin sandstones. | | |
| | 9,000 | Shales. | | |
| | 9,500<br>10,000 | Shales and sandstones. | *Inoceramus* sp.<br>*Amm.* (*Desmoceras*), sp. c. | |

| | Feet. | Rocks. | Fossils. |
|---|---|---|---|
| Knoxville beds. | 10,500<br>11,000<br>11,500 | Shales twisted and veined. | |
| | 12,000<br>12,500<br>13,000<br>13,500<br>14,000<br>14,500<br>15,000<br>15,500<br>16,000<br>16,500 | Shales with Calcareous layers. | *Belemnites impressus.*<br>*Ammonites* (*Desmoceras*) sp.<br>*Belemnites impressus.*<br>*Ammonites* (*Lytoceras*) *batesi.* |
| | 17,000<br>17,500<br>18,000<br>18,500<br>19,000<br>19,500<br>20,000<br>20,500<br>21,000<br>21,500<br>22,000 | Shales with Calcareous layers in places much folded. | Ferns and other plants.<br>(Locality *d.*) |
| | 22,500<br>23,000<br>23,500<br>24,000<br>24,500 | Shales and shaly sandstones with Calcareous layers. | |
| | 25,000<br>25,500<br>26,000<br>26,500<br>27,000<br>27,500<br>28,000 | Shales and shaly sandstones with small sandstones increasing. | *Aucella piochi.* |
| | 28,500<br>29,000<br>29,500 | Shales and thin sandstones. | |
| | 30,000 | | |
| | | Serpentine (Peridotite). | |

In the Knoxville beds shales predominate, although there are a large number of thin sandstones interstratified with the shales. The great majority of these sandstones are less than a foot in thickness, and they rarely, if ever, attain ten feet along the north fork of Elder creek. Sand-

stones are most abundant in the lower half of the Knoxville; in the upper half they are uncommon. Both north and south of Elder creek the Knoxville beds contain thick strata of conglomerate which do not appear in the measured section. The base of the section is serpentine, which has resulted from the alteration of an eruptive rock, in all probability belonging to the peridotites.* Ripple marks have been found in this portion of the section showing that the rocks were deposited in shallow water.

The shales of the Knoxville beds, with occasional thin layers of sandstone, continue upward without any interruption either in the character of the sediments or in the position of the strata, into the Horsetown beds. On account of the gradual transition in all respects from the Knoxville to the Horsetown beds it is impossible to draw a sharp line between them. *Aucella* being the most abundant, widely distributed and characteristic fossil of the Knoxville beds, it seems best to draw the line upon a paleontological basis at the upper limits of the *Aucella*-bearing layers. At that horizon fossils are usually abundant.

The Horsetown beds in this section are composed chiefly of shales, although there are some sandstones of considerable size. One was observed 50 feet in thickness, another 12 and a third 8 feet. Few fossils were found in these beds along Elder creek, but a short distance to the southward in the Bald hills, immediately above the Knoxville, they are more fossiliferous and contain the Horsetown species mentioned on page 446. Several miles east of Lowreys, on Elder creek, the basal portion of the Chico is rich in fossils. Here is found an intermingling of numerous Chico and Horsetown forms.

The Chico, which has a thickness of nearly 4,000 feet in this section, is composed chiefly of sandstones and conglomerates. The basal portion is made up of conglomerates altogether. The upper portion for 1,100 feet is composed chiefly of shales, and there are some shales lower down intercalated between the sandstones and conglomerates. The conglomerates at the base contain numerous nodules of limestone which are rich in fossils. Here was found *Coralliochama orcutti*, the characteristic Wallala fossil, in exactly the position predicted for it by Dr White. Its occurrence in the basal portion of the Chico of this section, as well as others upon the western border of the Sacramento valley with a large number of Chico fossils, completely demonstrates, as already urged, that the Wallala beds are only a phase of the Chico.

*A few miles southwest of Paskenta, by the road to Round valley, a large dike of serpentine appears to cut directly across the Knoxville beds, and there can be but little, if any, doubt, as shown also by Fairbanks (American Geologist, March, 1892) and Turner (Bull. Geol. Soc. Am., vol. 2, pp. 318-402), that the serpentine of the Coast range are altered eruptive rocks younger than the Knoxville portion of the Shasta-Chico series.

### *SECTION ON COLD FORK OF COTTONWOOD CREEK.*

The Cold fork of Cottonwood creek is about 15 miles north of Elder creek. The section it affords was not measured, but was examined several times with some care. At this point the *Aucella* beds are not so thick as on Elder creek, and yet they must be in the neighborhood of 10,000 feet thick, for they are exposed with a steep dip over a belt of country 3½ miles in width across the strike. The basal beds are shales with local conglomerates and rest directly with a conspicuous unconformity upon the metamorphic rocks. In the adjacent hills the metamorphic rocks are found, and among them are a number of limestones. One of these has afforded an imperfect *Chætetes*, which Mr Walcott has referred to the Carboniferous. The basal conglomerates of the Knoxville series contain pebbles of these limestones.

*Aucella* was discovered in this region by Mr H. W. Fairbanks. It occurs rather abundantly in the upper portion of the Knoxville beds. Five-eighths of a mile up a small ravine which enters Cold fork just above Mr Stephenson's house *Aucella* was found in the same bed with numerous other fossils noted on page 449, so that there can be no doubt whatever concerning their association.

The overlying beds in this section differ somewhat from those on Elder creek in containing a fetid limestone about 30 feet in thickness. It contains *Ammonites* (*Olcostephanus*) *deansii*, Whiteaves; *Atresius liratus*, Gabb (?); *Modiola major*, Gabb, and *Cyprina* (?), n. sp., and is probably about the same horizon as one of the limestones reported by Whitney and others in Colusa and adjoining counties to the southward, where they are said to be closely related with the *Aucella* beds.*

### *SECTION ON NORTH FORK OF COTTONWOOD CREEK.*

This section has been measured and is given in the accompanying table. It is well exposed along the north fork of Cottonwood creek and its branches above Gas Point. In the vicinity of Ono the Horsetown beds rest with marked unconformity directly on the metamorphic rocks. At the base there is a heavy conglomerate which is derived directly from the metamorphic rocks near by. *Aucella* has not been found in this section, though the fossils of its basal portion are identical with those that occur in beds adjoining the *Aucella* beds in the Bald hills near Elder creek. The Horsetown beds in this section have a thickness of 5,200 feet, and consist chiefly of shales and thin sandstones. They have afforded a large number of fossils, many of which have already been described by the paleontologists of the Geological Survey of California.

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* See references by Gabb in Paleontology of California, vol. ii, pp. 192, 195, 204.

| | Feet. | Rocks. | Fossils. | |
|---|---|---|---|---|
| | | | *Nucula truncata.* | |
| Chico beds. | 500 | Shales. | *Nucula truncata.*<br>*Ammonites (Schloenbachia) chicoensis.* | |
| | | Sandstones and shales. | Same as above. | |
| | 1,000<br>1,500<br>2,000 | Shales, with occasional thin beds of sandstone. | *Inoceramus whitneyi.*<br>*Pecten*, sp. a.<br>*Potamides tenuis* (?)<br>*Lunatia*, sp.<br>*Trochosmilia*, sp.<br>*Amm. (Lytoceras) sacya* (?) | |
| | 2,500 | Conglomerate and sandstone. | .......................... | *Pecten operculiformis.*<br>*Cucullæa truncata.*<br>*Trigonia evansana.*<br>*Meekia sella.*<br>*Chione varians.*<br>*Caryatis nitida.*<br>*Gyrodes expansa.*<br>*Anchura californica.*<br>*Cinulia obliqua.*<br>*Ammonites (Acanthoceras)*, sp.<br>*Amm. (Desmoceras)*, sp. a. |
| | 3,000 | Shale. | | |
| | | Conglomerate and sandstone. | | |
| | 3,500 | Shale. | *Pecten operculiformis.*<br>*Exogyra parasitica.*<br>*Nemodon vancouverensis.*<br>*Cucullæa truncata.*<br>*Trigonia evansana.*<br>*Trigonia leana.*<br>*Coralliochama orcutti.* | *Anchura falciformis.*<br>*Amm. (Desmoceras) hoffmanni* (?)<br>*Amm. (Desmoceras)*, sp. a.<br>*Amm. (Desmoceras)*, sp. b. |
| | | Sandstone and shale. | | |
| Horsetown beds. | 4,000<br>4,500<br>5,000<br>5,500<br>6,000 | Shales, considerably disturbed, without prominent bed of sandstone. | .......................... | *Exogyra parasitica.*<br>*Cucullæa truncata.*<br>*Lunatia avellana.*<br>*Amm. (Schloenbachia) inflata.* |
| | | | *Crioceras percostatus.*<br>*Ancyloceras lineatus.* | |
| | | | *Turnus plenus.*<br>*Amm. (Desmoceras) hoffmanni.*<br>*Crioceras percostatus.* | |
| | 6,500 | Sandstone. | .......................... | *Pecten operculiformis.*<br>*Nemodon vancouverensis.*<br>*Trigonia leana.*<br>*Trigonia æquicostata.*<br>*Diptychoceras lævis.* |
| | 7,000<br>7,500<br>8,000 | Shales, with thin beds of sandstone near base. | *Amm. (Lytoceras) batesi.*<br>*Amm. (Desmoceras) hoffmanni.*<br>*Amm. (Phylloceras?) ramosus.*<br>*Amm. (Hoplites) remondi.*<br>*Ancyloceras remondi.* | |
| | | | .......................... | *Pecten operculiformis.*<br>*Oxytoma mucronata.*<br>*Plicatula variata.*<br>*Nemodon vancouverensis.*<br>*Trigonia æquicostata.*<br>*Pleuromya lævigata.*<br>*Lunatia avellana.*<br>*Helicaulax bicarinata.*<br>*Potamides diadema.*<br>*Belemnites impressus.* |
| | | Sandstone. | *Pecten operculiformis.*<br>*Plicatula variata.*<br>*Nemodon vancouverensis.*<br>*Trigonia æquicostata.*<br>*Pleuromya lævigata.*<br>*Lunatia avellana.*<br>*Potamides diadema.*<br>*Ammonites (Lytoceras) batesi.*<br>*Diptychoceras lævis.*<br>*Belemnites impressus.* | |
| | 8,500 | Shales. | | |
| | | Conglomerate. | | |
| | 9,000 | Diorite. | | |

The Chico beds of this section, extending from a short distance above the mouth of Hulen creek to Gas Point, have a thickness of 3,600 feet. In the basal portion, as on Cold fork and Elder creek, conglomerates and sandstones prevail, but with a thickness deminishing northward. They contain near the bottom a large number of characteristic Chico fossils, and associated with these at this point, as well as on Cold fork and Elder creek, have been found the characteristic Wallala form, *Coralliochama orcutti*.

At Gas Point the topmost Chico beds are unconformably overlapped by the post-Cretaceous deposits which fill the Sacramento valley. It is not probable, however, that much of the section is covered, for upon the eastern side of the Sacramento valley, where the upper portion of the Chico is exposed, the fossils indicate approximately the same horizon as the beds at Gas Point. No trace of the Téjon has yet been found in California north of the fortieth parallel.

## Faunas of the Series.

### *CHICO FAUNA.*

The Chico fauna is most typically developed at Pence's ranch, Butte creek, Chico creek and other localities along the eastern border of the Sacramento valley, where it was first recognized by the California Geological Survey. A great many species were described from this region by Mr W. M. Gabb, a few were described earlier by Dr Trask, and some additions to the fauna have since been made by Dr C. A. White. The strata exposed at these localities are comparatively thin, and on structural grounds they are correlated with the upper portions of the beds referred to the Chico in the sections on the west side of the Sacramento valley. This correlation is supported by the fact that the few fossils, such as *Ammonites* (*Schloenbachia*) *chicoensis* and *Nucula truncata*, found only in the upper parts of these sections, are common at the typical localities above referred to, though the very small number of species makes the comparison with the rich fauna of the east side of the valley less satisfactory than is desirable. On the other hand, the lower 1,000 feet of the Chico in the measured sections are very fossiliferous, and the fauna they have yielded, though not as large as that of the typical Chico localities, has many species in common with it, together with some that have not been found there. Such species as *Cucullæa truncata*, *Trigonia evansana*, *Trigonia leana*, *Meekia sella*, *Pectunculus veatchi*, *Chione varians*, *Anchura falciformis* and others that are common on the east side of the valley occur at the very base of the Chico. This comparatively small change in the fauna indicates that the Chico was a period of rapid sedimentation

in the Sacramento valley, and that the advancing shore of the transgressing sea furnished a uniformly favorable habitat for its littoral fauna.

The lists of the more important fossils given in the tabular descriptions of sections on Cottonwood and Elder creeks show that the Chico fauna ranges through nearly 4,000 feet of strata.

A few of the species in the lower half of the Chico are worthy of special mention. The occurrence of *Coralliochama orcutti* at about the same horizon in all the sections examined fixes the position of the Wallala beds in the lower part of the Chico.

The following occur also in the Horsetown beds, some of them ranging down to the base of that division:

*Pecten operculiformis.*
*Exogyra parasitica.*
*Cucullæa truncata.*
*Nemodon vancouverensis.*
*Trigônia leana.*
*Trigonia æquicostata* (?)
*Meekia sella.*
*Chione varians.*
*Lunatia avellana.*
*Ammonites* (*Desmoceras*) *hoffmanni.*
*Ammonites* (*Desmoceras*) sp. a.

### *HORSETOWN FAUNAS.*

*Upper Horsetown.*—In the sections described the very close connection of the Chico with the preceding Horsetown fauna is not fully shown, because the upper part of the Horsetown beds is not very fossiliferous along the measured sections. At Horsetown and Texas springs, however, only a few miles northeast of the Cottonwood section many fossils have been found that evidently belong very near the top of the Horsetown beds. Lists of species from these localities showing a commingling of the Horsetown and Chico faunas have already been published.* The collections of the past season at these places have added three interesting species of ammonites, viz: *Lytoceras sacya*, Forbes, which is evidently identical with the Queen Charlotte specimens referred to that species; a *Desmoceras* (the same as the one in the Chico listed as *Ammonites* (*Desmoceras*), sp. a), that seems referable to *Desmoceras beudanti*, Brongiart, which also occurs in the Queen Charlotte formation; and an *Acanthoceras* that resembles one of the forms of *Acanthoceras mammillare*, Schloth., figured by d'Orbigny.† In connection with these species the *Schloenbachia inflata*, Sowerby, from the top of the Horsetown on Cottonwood creek may be mentioned. This species is reported from the Queen Charlotte formation and it occurs in the Ootatoor group of southern India. Stoliczka's figure ‡ seems to agree in every particular with our California specimen which was found associated with two Chico species only a short distance below the assumed base of the Chico. These ammonites, together with

*Bull. Geol. Soc. of Am., vol. 4, pp. 210, 250.
† Pal. Francaise Terr. Crétacé, t. 1, pl. 73.
‡ Palæontologia Indica, vol. 1, pl. 27.

*Ammonites* (*Desmoceras*) *breweri* and many species of other classes of mollusca that are associated with them in both California and Queen Charlotte islands, show that at least a part of the lower shales or division *C* of the Queen Charlotte Cretaceous may be correlated with the extreme upper portion of the Horsetown beds, if not with the base of the Chico. They also show indirectly that the upper part of the Queen Charlotte formation and the Vancouver formation must be closely related, since the latter holds the same fauna as the typical Chico; that is, the Vancouver fauna should immediately succeed the latest portion of the Queen Charlotte fauna, instead of being separated by the time interval required for the deposition of the 3,500 feet of strata in divisions *A* and *B* of the Queen Charlotte islands section.

Three of the ammonites above mentioned and a number of other species are represented by identical or closely related forms in the Ootatoor group of India, which is usually correlated with the European Cenomanian, and a similar fauna is found in the Cretaceous of Japan and Saghalin. These forms indicate that in Cretaceous time the faunas of the Pacific were able to migrate from one side of the ocean to the other, probably through the shallow waters of high northern latitudes, and thence along the shores on either side.

*Lower Horsetown.*—The lower Horsetown beds are characterized by a greater abundance and variety of ammonites with a smaller proportion of other mollusca, though in the occasional sandstone beds that occur in the shales down to the base the fossils are more closely related to the littoral faunas of the upper Horsetown and Chico, and several of the species seem to range through the entire division. There is certainly no faunal break within it. This portion of the Horsetown also is represented at many localities in the lower shales of Queen Charlotte islands.

The exposures below the Chico in the Elder Creek section have not yielded many fossils, but in the Bald hills, two to four miles south of Elder creek, several fossiliferous localities were found, both in the Horsetown and in the Knoxville beds.

At one of these localities near Wilcox's ranch a zone at the base of the Horsetown, not more than from 50 to 200 feet above the Aucella beds, yielded many species that are characteristic of the lower 1,500 feet of the Cottonwood Creek section. They include—

*Pecten operculiformis*, Gabb.
*Plicatula variata*, Gabb.
*Nemodon vancouverensis*, Meek.
*Pleuromya lævigata*, Whiteaves.
*Potamides diadema*, Gabb.
*Helicaulax bicarinata*, Gabb.
*Actæon impressus*, Gabb.
*Lunatia avellana*, Gabb.
*Amm.* (*Lytoceras*) *batesi*, Trask.
*Amm.* (*Phylloceras ?*) *ramosus*, Meek.
*Amm.* (*Olcostephanus*) *traski*, Gabb.
*Amm.* (*Olcostephanus*), sp. a.
*Crioceras percostatus*, Gabb.
*Crioceras latus*, Gabb.
*Belemnites impressus*, Gabb.

*KNOXVILLE FAUNA.*

The beds immediately below this zone contain essentially the same fauna, with the addition of large numbers of *Aucella* (the most characteristic fossil of the Knoxville) and a few other forms. At a locality about two miles north of Wilcox's ranch the following fossils were found in the uppermost strata of the Knoxville beds:

*Aucella crassicollis*, Keyserling; abundant.
*Aucella piochii*, Gabb, var *ovata*; rare.
*Inoceramus*, sp. undetermined.
*Helicaulax bicarinata*, Gabb.
*Ammonites* (*Lytoceras*) *batesi*, Trask.
*Ammonites* (*Olcostephanus*), sp. a.
*Crioceras latus*, Gabb.
*Belemnites impressus*, Gabb.

The Aucellæ play so important a part in the Knoxville fauna that it is necessary to insert here a few notes on their variations and stratigraphic range.

*Aucellæ of the Knoxville Beds.*—The most characteristic and by far the most abundant fossils of the Knoxville beds are the various forms of the genus *Aucella*. In many places the rocks are completely filled with them, and they are known to range through almost the entire great thickness of the beds. These Aucellæ show a great variety of forms and sizes, but they are easily separable into two groups that are in a general way characteristic of different horizons. One of these groups, which includes the typical form of *Aucella piochii*, Gabb,* is characterized by its slender, oblique form, and is very inequivalve, the left valve being convex, with a long, narrow, incurved beak, while the right valve is nearly flat, and its beak also is narrow. Occasionally a specimen shows faint, radiating striæ, suggesting the older *Aucella erringtoni* of the Mariposa beds. Of the Russian species, *Aucella mosquensis* is its nearest relative, but as there are several differences in form, especially of the umbonal region, it is preferable to leave them under Gabb's name, which was proposed about thirty years ago.

At the lowest horizon in the Knoxville beds from which we have collected in this region the typical *Aucella piochii* occurs alone, but in higher strata, about 3,000 or 4,000 feet below the top of the Knoxville, it is associated with a larger, more convex variety that may be compared with *Aucella mosquensis*, var. *ovata*, or with *Aucella terebratuloides*.† This variety occurs sparingly at first, and at a horizon about 1,000 feet higher it becomes the prevailing form. For convenience this variety is called *Aucella piochii*, var. *ovata*, but it should be stated that there is great individual variation, so that it is difficult to assign limits to any variety or species that may be proposed.

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* Figured in Paleontology of California, vol. i, pl. 25, fig. 173.

† See Lahusen, J.: Ueber Russischen Aucellen, Mém. Com. Geol., vol. 8, no. 1, St. Petersburg, 1888, where the Russian species are all figured and described.

At the horizon just mentioned, about 2,000 feet below the top of the Aucella beds, where *A. piochii*, var. *ovata*, is the most abundant form, the first representatives of the second general group of forms of the type of *A. crassicollis*, Keyserling, occur. This includes all the broad, robust, inflated forms in which both valves are almost equally convex and nearly equal in size, such as the forms figured by Gabb * and referred to *Aucella piochii.* Aucellæ of this type occur sparingly at the above-mentioned horizon, the lowest at which they have been observed, while they are the dominant and almost exclusive forms in the upper 1,000 or 1,500 feet of Knoxville beds, only occasional specimens that can be referred to *Aucella piochii*, var. *ovata* occurring with them. In Russia, according to Lahusen, all the Aucellæ occurring in the Cretaceous belong to this group. He recognizes the following species among them: *Aucella crassicollis*, *A. crassicollis*, var. *solida; A. crassicollis*, var. *gracilis; A. bulloides*, *A. keyserlingi*, *A. piriformis* and *A. piriformis*, var. *majuscula;* also *A. inflata* from the upper Volgian, which is by most authors referred to the Jurassic. Nearly all of these forms can be duplicated in our collections from the Knoxville beds, but as it does not seem possible to separate these California specimens into definable species, they will be referred to *Aucella crassicollis*, Keyserling, which is the earliest valid name † that has been applied to the group.

Dr C. A. White and Mr J. F. Whiteaves in describing the American Aucellæ have both recognized the varietal importance of the two general groups of forms here described. The facts as to their stratigraphic range as we have now determined them justify their recognition as species, even though they are genetically related and connected by many intermediate forms.

It is an interesting fact that the various forms of *Aucella* have appeared in this country in approximately the same order of succession that has been determined by Lahusen for the Russian forms, though if, as we believe, all the Knoxville beds are Cretaceous, they persisted longer here, and each stage of development was considerably later. Lahusen states that in Russia all the slender elongate species like *Aucella mosquensis* are confined to the Jurassic, beginning with the striated *A. bronni* in the beds with *Cardioceras alternans.*

*Other Knoxville Fossils.*—The brief lists of fossils from the Bald Hills region already given are sufficient to show the intimate connection of the upper Aucella beds with the Horsetown. Other localities in the

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* Paleontology of California, vol. ii, pl. 32, figs. 92*a*, *b*, *c*.

† Fischer de Waldheim in Oryctographie de Moscou first described and figured such forms under the name *Inoceramus concentricus*, Parkinson. Subsequent authors, finding that Fischer's specimens belonged to a different genus, as well as a different species, have quoted them as *Aucella concentrica*, Fischer, a practice that is unjust as well as confusing. Lahusen has proposed the name *A. piriformis* for the same specimens.

upper part of the beds, with *Aucella crassicollis* in the same neighborhood, have yielded the same forms of *Aucella* with *Ammonites* (*Olcostephanus*), sp. b, related to *Olcostephanus discofalcatus*, Lahusen; *Ammonites* (*Hoplites*), sp. a, related to *Hoplites ambligonius*, Neumayr and Uhlig; *Belemnites impressus*, Gabb; *Leda*, *Astarte*, *Pentacrinus*, etcetera.

The most northerly locality in the Sacramento valley at which *Aucella* has been found is near Stephenson's, on the Cold fork of Cottonwood creek. The horizon is probably very near that of the places just mentioned, and *Aucella crassicollis* is here associated with *Belemnites impressus* and species of *Pentacrinus*, *Rhynchonella*, *Ostrea*, *Lima*, *Nemodon*, *Leda*, *Trigonia*, *Opis*, *Astarte*, *Corbula*, *Helcion*, *Pleurotomaria* and others, none of which can be positively identified with described species, though forms closely related to several of them occur in the Horsetown beds.

Lower in the Knoxville beds Aucellæ occur at many horizons almost everywhere, but other fossils have been found associated with them at only a few places. On McCarty creek, a short distance north of Paskenta, about 1,000 feet below the top of the Aucella beds specimens of *Ammonites* (*Desmoceras*), sp., related to *Desmoceras breweri* and *Ammonites* (*Hoplites*), sp. b, were found associated with *Aucella crassicollis*.

In the same neighborhood, probably more than 2,000 feet lower, there is a small limestone that has yielded a number of species, including the following.

*Aucella piochii*, Gabb; abundant.
*Aucella piochii*, Gabb, var. *ovata*; rare.
*Nucula*.
*Cyprina*.
*Rhynchonella*.
*Turbo*.
*Chemnitzia* (?)
*Ammonites* sp.
*Belemnites*.

On the South fork of Elder creek, near Cooper's, at nearly the same horizon as the last locality, several species have been collected, as follows:

*Aucella piochii*, Gabb; very abundant.
*Aucella piochii*, Gabb, var. *ovata*; rather rare.
*Ammonites* (*Hoplites*) sp. c; related to *Hoplites* sp. a.
*Ammonites* (*Lytoceras*) *batesi*, Trask (?) Mere fragments with the form of this species.
*Ammonites* sp. Same as the ammonites from last-mentioned locality, having the form of *Ammonites* (*Phylloceras?*) *ramosus*, Meek.
*Belemnites* sp.; fragments.

A few hundred feet higher in the same section, where *Aucella piochii*, var. *ovata*, is the predominant form, several imperfect specimens of an *Ammonites* (*Perisphinctes*) were collected, and at a still higher horizon, where *Aucella piochii*, var. *ovata*, is very abundant, a few small specimens of *Aucella crassicollis* occur with a slender undescribed species of *Belemnites*. In addition to those mentioned, two other species of *Hoplites* are known from the Knoxville beds.

These notes will serve to show that the Knoxville fauna is closely connected in its later portions with the succeeding Horsetown fauna, and that we have no evidence of any faunal break within it, though there is a progressive change in the forms from the lower portions to the top. Of the Cephalopoda at least four species (*Lytoceras batesi*, *Olcostephanus* sp., *Crioceras latus*, and *Belemnites impressus*) pass up into the overlying Horsetown beds, and two other Horsetown species (*Desmoceras breweri* and *Phylloceras* (?) *ramosus*) are represented in the Knoxville by fragmentary specimens that belong to the same or closely allied species. The other Knoxville ammonites, consisting chiefly of *Hoplites*, seem to be most closely related to Neocomian species, though several of them are comparable with European Upper Jurassic (Tithonian) forms. A few of the species belonging to other classes seem to have Jurassic affinities, so it is probable that the oldest Cretaceous is represented in the Knoxville. The undoubted Cretaceous age of the upper part of this division and its evident unbroken continuity make it most natural and reasonable to assign the whole of it to the Cretaceous system. Compared with the fauna of the Mariposa beds, which is of late Jurassic age according to the recent investigations of Professors Hyatt and Smith, it seems to be totally distinct, excepting that the genus *Aucella* is present in both.

A paper in preparation will contain descriptions and illustrations of all the known species from the Knoxville beds, and more definite comparisons and correlation will there be attempted.

## Flora of the Series.

During the last field season a number of fossil plants were collected in Tehama and Shasta counties of California, chiefly from the Horsetown beds. They were referred for study to Professor W. M. Fontaine, who has identified the species given in the following list:

| | Locality. | | Locality. |
|---|---|---|---|
| *Sagenopteris mantelli.* | *a.* | *Cladophlebis inclinata* (?) | *d.* |
| *Pterophyllum californicum*, n. sp. | *a.* | *Osmunda dicksonioides* (?) | *d.* |
| *Angiopteridium canmorense* (?) | *b, d, e.* | *Angiopteridium strictinerve* (?) | *d.* |
| *Cephalotoxopsis magnifolia* (?) | *b.* | " *nervosum* (?) | *d.* |
| *Glossozamites klipsteini.* | *b, d.* | *Aspidium dunkeri* (?) | *d.* |
| *Abietites* (?) | *c.* | " *heterophyllum.* | *d.* |
| *Dioonites buchianus*, var. *rarinervis* (?) | *c.* | *Aspleniopteris pinnatifida* (?) | *d.* |
| *Equisetum texense* (?) | *c.* | *Thinnfeldia variabilis* (?) | *d.* |
| *Pecopteris strictinervis* (?) | *d.* | *Dioonites buchianus*, var. *angustifolius.* | *f, g.* |
| *Thyrsopteris rarinervis* (?) | *d.* | *Abietites angusticarpus.* | *h.* |
| *Nageiopsis longifolia* (?) | *d.* | *Sagenopteris latifolia.* | *i.* |
| *Sagenopteris*, sp. (?) | *d.* | *Abietites californicus*, n. sp. | *j.* |
| *Cephalotaxopsis*, sp. (?) | *d.* | *Dioonites dunkerianus.* | *j.* |

The localities from which the plants were collected are as follows:

| | | |
|---|---|---|
| *a.* | Tehama county, | Bald hills, east of Wilcox's ranch, top of the Knoxville beds. |
| *b.* | " " | Bald hills, near Wilcox's ranch, base of the Horsetown beds. |
| *c.* | " " | near the school-house southwest of Lowreys, upper portion of Knoxville beds. |
| *d.* | " " | north fork of Elder creek, above Woody's ranch, upper portion of Knoxville beds. |
| *e.* | " " | Cold fork, near Stephenson's, upper portion of Knoxville beds. |
| *f.* | Shasta " | Byron gulch, west of Ono, near base of Horsetown beds. |
| *g.* | " " | Byron gulch, near Ono, lower portion of Horsetown beds. |
| *h.* | " " | north fork of Cottonwood creek, below mouth of Eagle creek, middle portion of Horsetown beds. |
| *i.* | " " | Eagle creek, near Ono, lower portion of Horsetown beds. |
| *j.* | " " | one and a half miles northeast of Horsetown, upper part of Horsetown beds. |

Professor Fontaine remarks that—

"Whatever may be thought of the value of the preceding identifications, it is at least clear that we have in these twenty-six plants different forms. All have their nearest relations in Lower Cretaceous forms, and there is no plant that would indicate an age different from Lower Cretaceous. This alone is strong evidence of the age of the strata, and it is perhaps a better indication than would be identical species, if few in number and not of well marked character.

"But there are some of the plants that are well enough preserved and of sufficiently decided character to permit us to gain some positive proof of age. These are *Sagenopteris mantelli*, *Abietites angusticarpus*, *Dioonites buchianus*, var. *angustifolius*; *Dioonites dunkerianus*, *Aspidium heterophyllum*—five out of twenty-six. Then, *Pterophyllum californicum* and *Abietites californicus* are so much like Lower Cretaceous species that they are in fact representative of them. There can be no hesitation in regarding the plants collected from the Shasta group as being of Lower Cretaceous age."

The plants to which the above statements refer were collected from various horizons ranging through nearly 8,000 feet of strata from within the upper portion of the Knoxville to nearly the top of the Horsetown beds and include none which are dicotyledonous. The only dicotyledonous plant in our collections came from the lower portion of the Chico beds on Elder creek, where a single specimen was obtained.

## Unity of the Series.

The three sections of the Shasta-Chico series already given show conclusively that there is complete continuity from the bottom of the Knoxville to the top of the Chico. The strata, where all are well exposed in

the same section, are conformable throughout,* and the character of the sediments is also the same. There can be no further doubt concerning the continuity of life throughout the series. Several successive faunas are recognizable, but they are all closely bound together by many commingling species. The Shasta-Chico series, including the Wallala beds, may therefore be considered as a unit in discussing the geology of the Pacific coast.

There is, however, one other argument for its unity to which it is desired to call attention. On the eastern side of the Sacramento valley the Chico beds rest with a conspicuous unconformity directly on the metamorphic rocks of the auriferous series. About the northern end of the Sacramento valley the same is true, but as we move southwestward from Redding, along the foot of the Klamath mountains and Coast range, we find successively older and older beds coming in below and resting with this marked unconformity on the metamorphic rocks. At Texas springs and Horsetown this great unconformity runs beneath the Horsetown beds. Farther south, on Cold fork and elsewhere, the same great unconformity runs beneath the Knoxville beds, so that the Chico, Horsetown and Knoxville beds all hold exactly the same relation to the great unconformity of that region, and thus furnish additional evidence that they belong to the same series.

## Distribution of the Series.

The unity of the Shasta-Chico series being admitted from the evidence already adduced, several consequences of importance follow from the vertical and horizontal distribution of the series.

An examination of these deposits in the field shows clearly that the Horsetown beds overlap the Knoxville northward along the western side of the Sacramento valley, and the Chico beds in like manner overlap the Horsetown in the same direction, so as to reach not only the western base of the Sierra Nevada, but extend northeastward between the Sierra Nevada and Klamath mountains far into Oregon, connecting, in all probability, with the Chico of the Blue mountains in that state, as well as with that of Washington, Vancouver and Queen Charlotte islands.

In Oregon also, as already noted in California, the Horsetown beds overlap the Knoxville, well exposed in the vicinity of Riddles, in Douglas county, and extend as far southeastward as Graves creek, where they rest

* Mr Fairbanks recognizes a small unconformity between the Knoxville and Chico beds, due to the eruption of the peridotitic rocks from which the serpentine has been derived (Eleventh Report State Mineralogist of California, p. 67; also American Geologist, March. 1892, p. 166); but the great unconformity which Dr Becker (U. S. Geol. Survey, Bulletin no. 19, p. 12) places at this horizon belongs below the Knoxville.

directly and with a marked unconformity on the metamorphic rocks. In like manner the Chico extends beyond the Horsetown in Oregon, for at Jacksonville and Ashland, southeast of the Horsetown locality on Graves creek, we find the Chico beds resting with a conspicuous unconformity directly on the metamorphic rocks. This overlapping to the northeast in California and southeast in Oregon finally resulted during the Chico epoch in connecting the two areas through Lassen strait,* which separated the Klamath mountains from the Sierra Nevada.

To the southward the Shasta-Chico series has been identified by Turner,† Lindgren,‡ White,§ Fairbanks,‖ and Dall¶ in the Coastal region as far as Todos Santos bay of Lower California. Emmons** and Merrill have recognized it as far south as 29° 30′, and believe it extends still further in the same direction.

## Deformations.

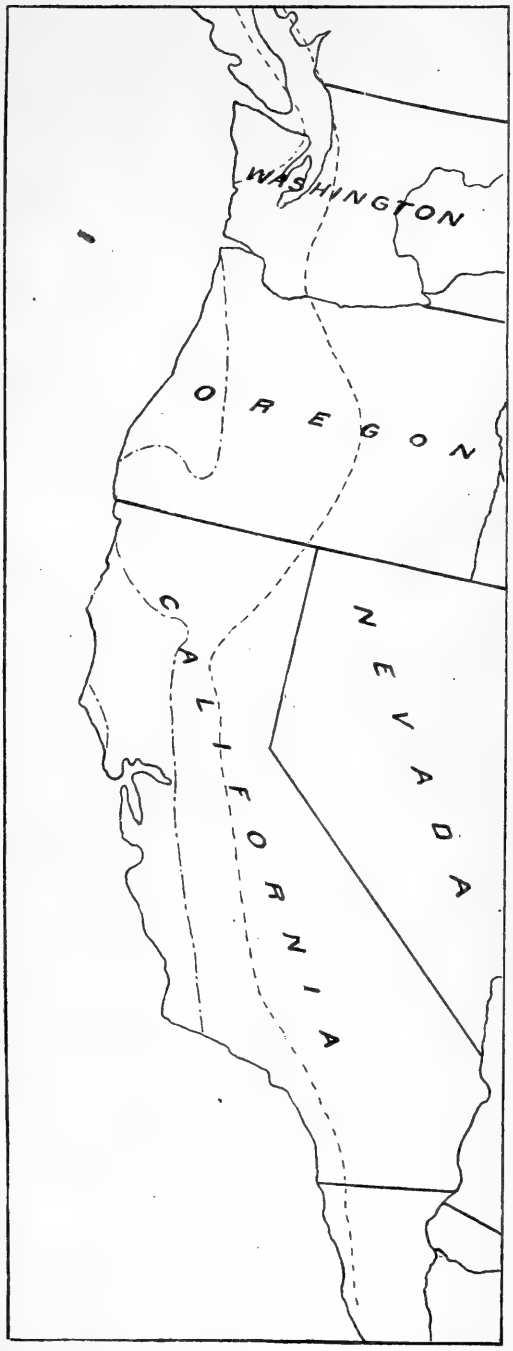
### *SUBSIDENCE DURING THE SHASTA-CHICO EPOCH.*

On the accompanying map are indicated the coast lines at the close of the Horsetown and Chico epochs. The Knoxville coast has been traced both in Oregon and northern California to but a limited extent. The same is true also of the Horsetown shoreline, which lay only a short distance farther inland, but during the Chico epoch the invasion of the sea reached its maximum and extended far inland, as indicated by the position of the coast line at the close of that time. This successive overlapping landward of the newer and newer beds of the Cretaceous system shows that during the period of deposition of the Shasta-Chico series the continent was subsiding and the sea transgressing.

Dr Dawson†† has shown from observations in British Columbia that a similar movement was in progress at the same time in that country. The sea was transgressing to the southward in the Puget Sound region during the Chico, and the concomitant subsidence was undoubtedly connected with that great invasion, which reached as far eastward as the Blue mountains, in Oregon.

To the south, as in the north also, the sea was evidently transgressing. From Tehama county, in California, the Knoxville, Horsetown and Shasta beds may be traced southward through Colusa, Napa and other counties

* U. S. Geol. Survey, Eighth Ann. Rep., p. 412.
† The American Geologist, May, 1893, pp. 307–324.
‡ Proc. Cal. Acad. Sci., 2d ser., vol. i, pp. 180–182.
§ U. S. Geol. Survey, Bulletins 22 and 82.
‖ Am. Jour. Sci., vol. xlv, pp. 475–477, June, 1893.
¶ Bull. Geol. Soc. Am., vol. 4, p. 207.
** Bull. Geol. Soc. Am., this vol., post.
†† Trans. Roy. Soc. of Canada, vol. viii, sec. iv, 1890, pp. 3–75.




— - — - = shoreline at close of the Horsetown epoch.
- - - - - - = shoreline at close of the Chico epoch.

FIGURE 1.—*Map showing approximately the Coast-lines at Close of Horsetown and Chico epochs.*

in the central portion of the state. There is evidence of the presence of the Horsetown beds at Benicia, for at that point *Ammonites batesii*, which is one of the characteristic fossils of the lower portion of the Horsetown beds, has been found. The Knoxville beds evidently extend farther to the southward, even as far southward as San Luis Obispo, where Mr Turner* has found *Aucella*, but they do not appear to reach the Santa Ana range of southern California, where Mr Fairbanks† reports that the Upper Cretaceous rests unconformably on the metamorphic rocks, in which, according to him, fossils, probably Carboniferous, have been found. Farther southward only Chico fossils have been found, as far as yet definitely known, extending in that direction through Lower California to near the 29th parallel and perhaps even farther. There is evidence in this distribution of the Knoxville, Horsetown and Chico beds to the southeastward along the coast of southern California that the continent was subsiding in that direction, as it was to the northward, at least as far as Queen Charlotte islands.

The varying thickness of the formations furnishes corroborative evidence. The Knoxville, Horsetown and Chico beds all diminish in thickness to the northward from Elder creek; the Knoxville from

*U. S. Geol. Survey, Monograph xiii, p. 381.

† Am. Jour. Sci., vol. xlv, p. 478. Fairbanks suggests that, although no lower Cretaceous has yet been recognized in southern California, certain local fossiliferous beds on the summit of the Carrejo mountains, 70 miles east of San Diego, may be of that age.

nearly 20,000 to 10,000 feet (estimated) on Cold fork; the Horsetown from 6,100 to 5,200 feet, and the Chico from nearly 4,000 to about 3,600 feet on the north fork of Cottonwood creek. The thinning out is due to the fact that the newer beds overlap to the northward and eastward, and it is evident that all the members of the Shasta-Chico series thin out to an edge toward the Cretaceous land. This relation clearly indicates subsidence of the land and transgression of the sea.

To the southward also the Chico seems to be thinning, for in the region of San Diego, according to Mr Fairbanks, the Chico beds containing *Coralliochama orcutti*, which belongs to the very basal portion of the Chico, is conformably overlain by Eocene containing characteristic fossils of that horizon, and the two appear to be only 1,200 feet in estimated vertical distance apart.* The thickness of the Chico in that region therefore may not be greater than 1,200 feet, and if so, its thickness must have greatly diminished to the southward.

### *COAST RANGE UPLIFT AT CLOSE OF THE JURASSIC.*

Several years ago Mr H. W. Fairbanks † maintained the pre-Cretaceous age of the metamorphic rocks of the Coast range in California, and that the Coast range with the Sierra Nevada was upheaved at the close of the Jurassic.

There is evidence favoring the same conclusion, in that the thickness of the Shasta-Chico series diminishes westward from the Sacramento valley into the Coast range, as it does eastward to the base of the Sierra Nevada. Along the coast north of San Francisco, in the Wallala region, according to Becker,‡ the Chico (Wallala) beds, some thousands of feet in thickness,§ rest unconformably upon the metamorphic rocks. Mr Turner has studied the same region, and regards the Chico at that place as unconformable not only upon the serpentine, of which the conglomerate (Chico) is said to contain pebbles, but also upon the silicious slates and other pre-Cretaceous metamorphic rocks of the Coast range. The relation here is probably the same as it is upon the northern border of the Sacramento valley, where *Coralliochama orcutti* occurs in the Chico beds, which rest with conspicuous unconformity upon the metamorphics. Wherever the Chico beds overlap the Horsetown their basal portion containing the fossils of the horizon exposed near Wallala must come directly and unconformably in contact with the older metamorphic rocks.

The thinning out of the Shasta-Chico series westward from the Sacramento valley shows that the Coast range was uplifted at the close of the

* Am. Jour. Sci., vol. xlv, p. 476, June, 1893.
† American Geologist, March, 1892, and February, 1893.
‡ U. S. Geol. Survey, Monograph xiii, pp. 191, 194.
§ White: U. S. Geol. Survey, Bulletin no. 22, p. 7.

Jurassic, when the Sierra Nevada received its final folding and the great valley of California was outlined thereby. It cannot yet be definitely concluded that the Coast range and the Sacramento valley originated at the close of the Jurassic; their beginnings may date from earlier foldings; but whatever the date of inception, it is evident that during the Shasta-Chico period the Coast range existed, but did not furnish sufficient obstruction to keep the open sea out of the Sacramento valley, for the fossils of that period are everywhere purely marine. That a Coast range island continued in the Wallala region until the close of the Horsetown epoch is indicated by the absence of the Shasta portion of the series at that point. Further northward, however, the waters of the Horsetown epoch crossed between Bully Choop and Yallo Bally, which is now the principal divide west of the Sacramento valley, and connected directly with the open sea possibly in such a way as to separate the island of the Wallala region from that of the Klamath mountains.

Since the above was written a brief but important paper has been published by J. P. Smith,* who concludes from new faunal evidence that "the Mariposa slates are of Upper Jurassic age," and that "the uplift and metamorphism of the Sierra Nevada and of the Coast range occurred in late Jurassic time, before the deposition of the Cretaceous."

### *SUBSIDENCE OF THE SACRAMENTO VALLEY.*

The large extent of this subsidence, from Alaska on the north to Lower California on the south, makes it an epeirogenic movement. There is evidence, however, that the movement, although epeirogenic, was not uniform throughout the whole area.

In the accompanying ideal section there are represented the general observations made on Elder creek, Cold fork and North fork of the Cottonwood, as well as those on the eastern side of the Sacramento valley and at the western foot of the Coast range along the coast at Wallala, and it appears that the subsidence was greater in the Sacramento valley than in the region of the Coast range and Sierra Nevada.

At the time the basal portion of the Knoxville beds was deposited the water was shallow, for there are numerous local conglomerates and sandstones, some of which are ripple-marked. If the subsidence was uniform throughout the whole region it follows that what is now the western foot of the Sierra Nevada, as well as the corresponding portion of the Coast range, where in both cases the Chico rests directly upon the folded pre-Cretaceous rocks, must have been at an elevation of over 25,000 feet above the sea when the basal portion of the Knoxville was deposited in the

* "Age of the Auriferous Slates of the Sierra Nevada." Bull. Geol. Soc. Am., vol. 5, pp. 257, 258.

Sacramento valley. This hardly seems possible, for we know of no such enormous mountains in the country today. It seems much more probable that the subsidence was not uniform. The Sacramento valley, which then undoubtedly existed, flanked by the Sierra Nevada on one side and the Coast range on the other, was a region receiving a tremendous load of sediments from the mountains on both sides. In accordance with the isostatic condition of the earth's crust, it would be expected that the loading region—that is, the Sacramento valley—would sink, while the unloading region—that is, the Sierra Nevada and the Coast range—would gently rise, and in this way the enormous difference of elevation at the close of the Shasta-Chico period would easily be accounted for by supposing a much smaller original difference at the beginning of that period.

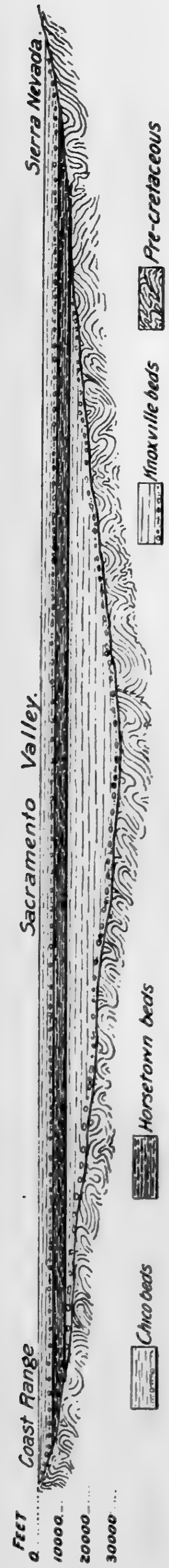



FIGURE 2.—*Ideal Section across the Sacramento Valley.*

The section is taken near the 39th parallel and from the western base of the Sierra Nevada across the Sacramento valley, and represents the supposed conditions at the close of the Shasta-Chico period. The vertical and horizontal scales are approximately 18 miles to 1 inch.

## Relation of Knoxville and Mariposa Beds.

The Mariposa beds, as shown by Whitney and others, are sometimes metamorphosed and infolded with the Auriferous slates, which are unconformably overlain along the western base of the Sierra Nevada by the Chico beds. Although the Chico beds have not yet been found in contact with the fossiliferous portion of the Mariposa beds, their relation is such between Folsom and Mariposa that, according to Becker,* Turner and Lindgren, there is no reason to doubt their unconformity. This unconformity, as already stated, can be traced around the northern end of the Sacramento valley and along its western border, where it passes successively beneath the Horsetown and Knoxville beds. The Mariposa and Knoxville beds, so far as yet known, occur nowhere upon opposite sides of the great valley within 30 miles of each other. There is good reason to believe, however, from their relation to

*U. S. Geol. Survey, Bulletin no. 19, p. 19.

the great unconformity that if ever found in contact they will probably not be conformable.

This view is supported by the latest investigation concerning the paleontologic relation of the two sets of beds. The Geological Survey of California recognized the fauna of the Mariposa beds as Jurassic and distinct from the Cretaceous of the Shasta group in the Coast range, although it should be said that the Aucella-bearing portion of the Knoxville had at that time yielded very few fossils other than *Aucella* and *Belemnites impressus*.

The studies of Dr White led him to regard the Aucellæ of both beds as essentially the same species.* Dr Becker accordingly made the Mariposa beds equivalent † to the Knoxville, and finally ‡ placed the post-Jurassic (Whitney) but pre-Chico upheaval of the Sierra Nevada and Coast range after the deposition of the Horsetown beds.

The complete faunal and stratigraphic intergradation which, as we § have shown, occurs wherever the Horsetown and Chico beds are found in contact, precludes the existence of a great unconformity between them at any point in northern California and renders it certain that the great upheaval took place before the deposition of the Shasta-Chico series.

Professor Hyatt, who has recently studied the fauna of the Mariposa beds and compared with it the Ammonites and Aucellæ of the Knoxville beds, authorizes us to say that in his opinion "the fauna of the Knoxville beds, on the one hand, is decidedly Cretaceous and clearly related to that of the Horsetown beds, but, on the other hand, is entirely distinct from that of the Mariposa beds."

This conclusion corroborates those drawn from the stratigraphic evidence and establishes upon a firmer basis the view long since entertained by Whitney that the upheaval and metamorphism of the Sierra Nevada occurred at the close of the Jurassic.‖

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* Ibid., Bulletin no. 15, p. 24.

† Ibid., Bulletin no. 19, p. 18.

‡ Bull. Geol. Soc. Am., vol. 2, p. 206.

§ Bull. Geol. Soc. Am., vol. 4, pp. 207–211 and 249–257.

‖ The Aucella beds of the Sierra Nevada are confined, as far as yet certainly known, to the lower portion of the western slope, and their general trend would carry them across the Sacramento valley to the Klamath mountains and Coast range just north of the 40th parallel, where the northern limit of the Knoxville beds in California is known to occur. The Aucella beds are not yet known in contact with the Taylorville Jurassic, which occurs not only upon the northern end of the Sierra Nevada, but also well developed in the Pit river region of Shasta county, California, as well as in southwestern Nevada and the Blue mountains of eastern Oregon (Bull. Geol. Soc. Am., vol. 4, p. 221; also vol. 5, p. 400). There may have been an upheaval of the Sierra Nevada either before or immediately after the deposition of the Taylorville Jurassic by which the Aucellæ were limited to the western part of that range, but the change of level may have been gentle and not accompanied by folding and metamorphosing of the involved strata.

## Time Range of the Series.

The recent investigations of Hyatt and Smith already referred to assign the Mariposa beds to late, though not the latest, Jurassic, while the paleontologic evidence we have given indicates that the Knoxville includes the earliest Cretaceous deposits. It is evident from the faunal relations of these two formations that their epochs of deposition were not separated by a long time interval, but it appears that during this interval the upturning of the Mariposa beds occurred, and some time must have elapsed.

The deposition of that series continued without a general interruption from the beginning of the Knoxville to the close of the Chico, and the time represented by the 30,000 feet of strata which accumulated during that interval must necessarily be long.

The Ammonites of the upper part of the Horsetown to which reference was made in the note on the fauna are either identical with or closely related to forms which in Europe are characteristic of the upper Gault and lowest Cenomanian. *Ammonites inflatus*, especially, is there regarded as the characteristic fossil of a zone that is now placed at the base of the Cenomanian. The other invertebrate fossils from these beds do not conflict with this evidence* of the Ammonites, and it is therefore safe to say that the Knoxville and Horsetown together represent all of the Lower Cretaceous—that is, everything from the Wealden and Neocomian to the Gault, inclusive, with perhaps a small portion of the Upper Cretaceous.

It is somewhat more difficult to fix the time range of the Chico. Its basal portions must have been deposited early in Upper Cretaceous time, but the time of its close is more uncertain. Its large and varied littoral fauna, with a few Ammonites, seems to have no species in common with the American Cretaceous faunas east of the Sierra Nevada, though it is true that several genera are represented in the Montana and Ripley formations (of Senonian age) by similar species; but the known American faunas corresponding to the European Cenomanian and Turonian are comparatively small and do not offer much basis for comparison. As an exception to this general statement we may cite a recently discovered littoral facies of the Fort Benton fauna, locally developed in southern

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* Professor Fortaine's study of the small collection of plants taken from several horizons ranging from within the Knoxville to near the top of the Horsetown shows that they are all related to forms in the floras of the Wealden, the Trinity and the Potomac, all of which he regards as oldest Cretaceous. The testimony of the invertebrates agrees with this in a general way, excepting that they show a later age for the upper part of the series. In such comparisons it is well to remember that the known plant-bearing beds do not form as complete and continuous a standard series as is furnished by those containing marine invertebrates, and for this reason correlations made on the evidence of plants alone are frequently not as definite as may be made by the Ammonites, for example.

Colorado, in which there are several species of both Gasteropoda and Pelecypoda that are related to Chico as well as to Ripley species. These are associated with *Inoceramus labiatus* in beds that may be correlated with the Turonian, and they are mentioned here simply to show that many of the Chico types which have been compared with species in the Ripley and Montana formations (Senonian) are also represented by related forms in earlier deposits.

The direct evidence from the Chico fossils cannot be presented fully at this time, as that would require the review of the entire fauna and the description of a number of new species obtained in recent collections. It is a significant fact that the most abundant Ammonites of the Chico belong to the genus *Schloenbachia* (in the broad sense in which the name is used in Europe). *Ammonites chicoensis*, *Ammonites tehamaensis* and two undescribed species belong here and these are all found in the upper beds of the Chico. In other American cretaceous areas this genus does not pass above the top of the Colorado formation and its equivalents, and in Europe it seems not to occur above the "Emscher Mergel" or lowest Senonian. *Ammonites turneri* which was found near Mount Diablo associated with *Anchura californica* and other lower Chico species is an *Acanthoceras* closely related to European species that occur in the Cenomanian. The other Ammonites known from these beds do not resemble those characteristic of the latest Cretaceous. The two abundant species of *Trigonia*, *T. evansana* and *T. leana* likewise have their nearest relatives in the lower part of the Upper Cretaceous of Europe.

The occurrence of *Inoceramus labiatus* in the upper shales (division A) of Queen Charlotte islands is also a suggestive fact in the same direction when considered in connection with the close relationship between the Shasta and the Chico, and consequently between the Queen Charlotte "Lower Shales" and the Chico. The equivalent of the Chico on Vancouver island has yielded a considerable flora which Sir William Dawson* assigns to the older part of the Upper Cretaceous, though he regards it as later than the Dakota. He states that "there would seem to have been a geographical separation between the Pacific coast and the plains, as the latter have not yet yielded anything equivalent to the Vancouver flora."

In Oregon the Téjon appears to overlie unconformably the Shasta-Chico series under such conditions as to suggest that a considerable period of erosion occurred between the uplifting of that series and the deposition of the Téjon. The faunas of the Chico and the Téjon as developed there are entirely distinct. The stratigraphic and faunal evidence tends to show that in the regions in which we have studied it the

* Fossil Floras and Climate. Nature, vol. 47, p. 557, April, 1893.

Chico does not represent the very latest Cretaceous time, perhaps not later than the close of the Colorado epoch, or the Turonian and earliest Senonian of Europe.

For the present, therefore, the Shasta-Chico series may be regarded as representing the whole of the Lower Cretaceous and the earlier half of the Upper Cretaceous, with the proviso that there may be still later Cretaceous beds in middle California where the Chico and Téjon are said to be conformable and their faunas have been reported to contain a number of common species.

## Correlation of the Series.

### *NANAIMO AND QUEEN CHARLOTTE ISLAND GROUPS.*

The earliest recognition of the Cretaceous upon the western coast of North America was by F. B. Meek,* who described some fossils from Vancouver island. The paleontologists of the Geological Survey of California † early recognized the beds from which these fossils came as Chico. They contain valuable beds of coal, and have received much attention from the members of the Geological Survey of Canada, especially from James Richardson, Dr G. M. Dawson and J. F. Whiteaves.‡ The name Nanaimo group was suggested § for the rocks in question, and the investigations of the Canadian geologists, in connection with those of the United States Geological Survey in California, Oregon and Washington, fully confirm the view that the Cretaceous rocks of the Nanaimo region are Chico.

The Queen Charlotte Island group, division C, D and E of Dr Dawson, has been correlated by Whiteaves with the Shasta. Our investigations in California and Oregon have increased the number of common species and leave no doubt that the Horsetown, and probably also the Knoxville portion of the Shasta-Chico series, is represented in the Queen Charlotte Island group. ||

### *POTOMAC.*

The Kootanie has been placed by Sir J. William Dawson ¶ on approximately the same horizon with Dr G. M. Dawson's subdivision C ** of the Queen Charlotte Island formation. According to Fontaine †† and Newberry ‡‡ the Kootanie and Great Falls beds of Montana are to be correlated with each other and also with the Potomac. This correlation,

* Transactions of the Albany Institute, vol. iv, 1857, pp. 37–49.

† Geol. Survey of California, Paleontology, vol ii, p. xiv.

‡ The Cretaceous System in Canada: Trans. Roy. Soc. of Canada, for 1893, sec. iv, 1893, pp. 1–19.

§ Am. Jour. Sci., vol. xxxix, March, 1890, pp. 180–183.

|| See ante, pp. 445, 446.

¶ Trans. Roy. Soc. of Canada, vol. iii, sec. 4, p. 20.

** Am. Jour. Sci., vol. xxxviii, 1889, p. 122.

†† Proc. U. S. Nat. Mus., vol. xv (1892), pp. 487–495.

‡‡ Am. Jour. Sci., vol. xli, March, 1891, p. 193.

which in a general way makes the Potomac equivalent to a part of the Shasta portion of the Shasta-Chico series, is greatly strengthened by Professor Fontaine's study of the flora. Of the twenty-two species of plants found in the Shasta beds, four, viz., *Dioonites buchianus*, var. *Angustifolius*, *Abietites angusticarpus*, *Sagenopteris latifolia* and *Aspidium heterophyllum*, have been determined as certainly identical with forms found in the Potomac. The one first named is the most abundant plant in the collection from the Shasta beds. Besides these, ten other species have been determined as probably identical with Potomac forms. If not identical they are at least closely related forms. Of some of these forms Professor Fontaine remarks that their identity is marked (?), not because he had any doubt in the matter, but because the amount of material was too small to justify a positive opinion.

### *COMANCHE SERIES OF TEXAS CRETACEOUS.*

This series, consisting mainly of limestones, which has a very great development in Texas and Mexico, underlies the equivalents of the Upper Cretaceous of the Rocky Mountains and Great Plains regions, and therefore holds the same stratigraphic position as the Shasta portion of the Shasta-Chico series. According to Mr R. T. Hill,* the lower portion (Trinity division) of the Comanche has an invertebrate fauna related to the Neocomian of Europe, and consequently of the same age as a part of the Shasta fauna, although these two faunas seem to have nothing in common, and if they were strictly contemporaneous must have been separated by a great land barrier, as White has suggested. The fossil plants furnish more direct evidence for this correlation. The Glen Rose beds, about 250 feet above the base of the Trinity division, have yielded a flora, described by Professor Fontaine,† that is very closely related to that of the older Potomac and contains one species certainly, and two others doubtfully, identified by Professor Fontaine in our recent collections from the Shasta.

The most promising field for the discovery of the direct relations of the Shasta to the Comanche is in southern Mexico, where it seems probable that portions of both series may yet be found together or their faunas intermingled. The Comanche series is known to cover a large part of Mexico, and the Shasta-Chico series certainly extends as far south as 29° 30′ on the Pacific coast. The Ammonites described by Dr J. Felix ‡ from the Neocomian near Tlaxiaco, state of Oaxaca, are related to some of those from the Knoxville beds, while those from Tehuacan, in Pueblo, seem to belong to the Comanche fauna.

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* Proc. Biol. Soc. of Washington, vol. 8, 1893, p. 20.
† Proc. U. S. Nat. Mus., vol. 16, 1893, pp. 261–282.
‡ Palæontographica, vol. 37, 1891, pp. 180-189.

There are also Aucella-bearing beds in that region that have been referred by Nikitin* and by Aguilera and Ordoñez† to the Jurassic, which is said by the latter authors to underlie the Cretaceous conformably. The Aucellæ mentioned by Nikitin (*Aucella pallasi*, var. *plicata*, and another with the form of *A. pallasi*, but with radiating sculpture stronger than that of *A. bronni*) are evidently like those of the California Mariposa beds. They came from San Luis Potosi. Aguilera and Ordoñez list six species and three varieties of *Aucella* under the head of Jurassic fossils, referring them all to Russian species, some of which occur in the older Aucella beds of Russia, while others, according to Lahusen, are confined to the Neocomian.

### *CORRELATIVE MOVEMENTS.*

From the general correlation of formations already made some movements of the land may be correlated.

During the lower Cretaceous the whole western half of the North American continent was subsiding and the sea transgressing. In most places this movement continued with or without interruptions during a part of the Upper Cretaceous.

The extensive conglomerate of the Sacramento valley which marks the basal portion of the Chico beds may have resulted from topographic changes connected with the intrusion of the peridotites whose alteration gave rise to the serpentines of the Coast range. It is not, however, certainly known that the eruption of the peridotites occurred at that time.

Between the Horsetown and Chico beds in California there is no unconformity corresponding to that reported by Hill between the Upper and Lower Cretaceous of Texas. It is evident, however, that at the time represented by that unconformity there were widespread topographic changes which are recorded, as noted by Dr Dawson,‡ in the extensive conglomerate of the Dakota group as well as in the Upper Cretaceous of Queen Charlotte islands and in the Chico beds of Oregon and California.

The great post-Laramie disturbance noted by Emmons§ in the Rocky mountain region corresponds to that represented by the unconformity between the Chico and Téjon of northern California and Oregon.

## Résumé and Conclusions.

The discovery of *Coralliochama orcutti* in the basal portion of the Chico beds at a number of points in the Sacramento valley completes the demonstration that the Wallala beds are only a phase of the Chico.

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* Neues Jahrb. für Mineral. Geol. und Palæont., Bd. 2, 1890, p. 273.

† Datos para la Geologia de México, 1893.

‡ Am. Jour. of Sci., vol. xxxviii, p. 125.

§ Bull. Geol. Soc. Am., vol. i, pp. 245–286.

The Shasta-Chico series is composed of the Knoxville, Horsetown and Chico beds, all of which are well exposed in the same sections upon the western border of the Sacramento valley.

The Knoxville, Horsetown and Chico beds are each characterized by its own fauna. The faunas of adjacent beds, however, are so bound together by many common species that there is no paleontologic break anywhere within the series.

The Shasta-Chico series is conformable throughout and the intergradational character of the sediments, taken in connection with the faunal continuity of the series and its relation to the great unconformity beneath, shows that it is the result of continuous deposition.

The attenuation of the Shasta-Chico series westward from the Sacramento valley and the overlapping of the newer beds upon the older crystalline rocks of the Coast range shows that the Coast range was formed before the deposition of the Shasta-Chico series, and probably at the close of the Jurassic when the Mariposa beds were upturned.

The successive peripheral attenuation of the lower beds and the landward overlapping of the upper ones shows that the Pacific coast from Alaska to Mexico was subsiding and the sea transgressing.

The subsidence was probably not uniform throughout the whole region. The deposition of 30,000 feet of sediments in the Sacramento valley under shallow-water conditions apparently indicates a greater subsidence in that region than for the mountains from which the sediments were derived.

The Mariposa and Knoxville beds are faunally distinct and unconformable. The former is Jurassic and the latter Cretaceous.

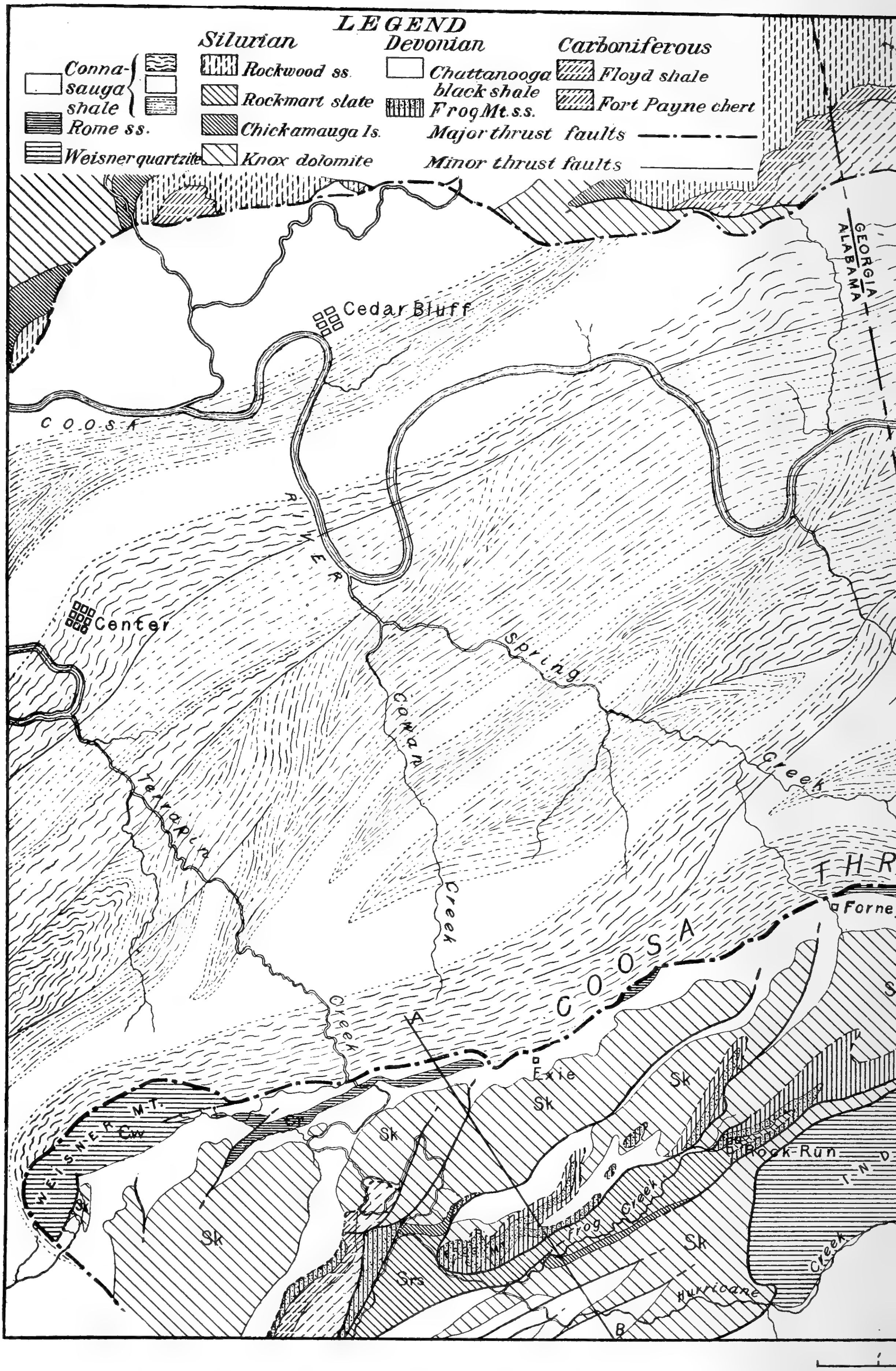
The final folding of the Sierra Nevada rocks and an uplifting of the range occurred at the close of the Jurassic.

The Shasta-Chico series represents the Cretaceous time from the beginning of the Lower Cretaceous to the middle of the Upper Cretaceous, and it may be closely correlated with the Queen Charlotte Island and Nanaimo groups.

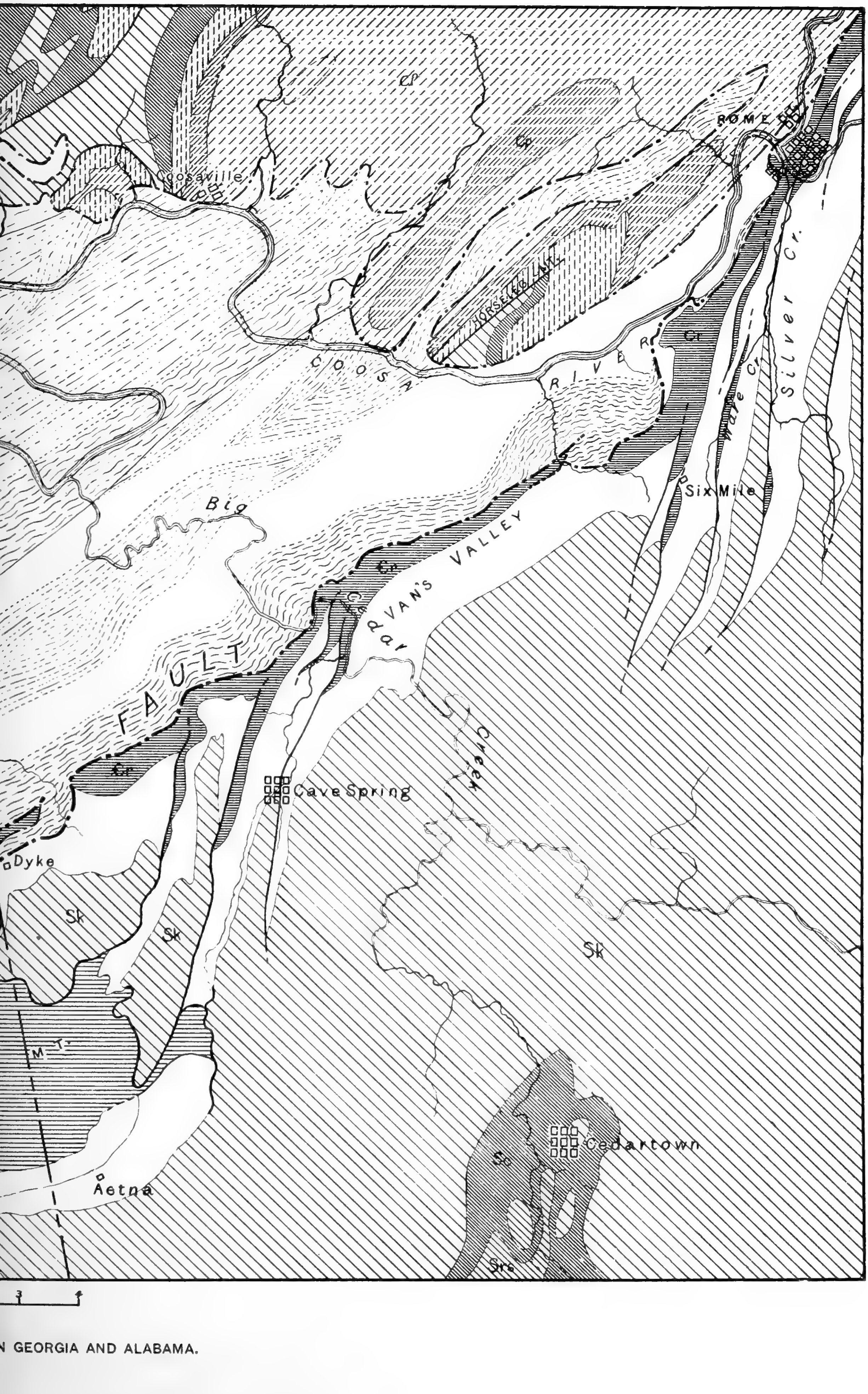
The fact that certainly 4 and possibly 14 out of 22 fossil plants found in the Knoxville and Horsetown beds of California are identical with forms found in the Potomac formation of the Atlantic border indicates that the Potomac epoch is included in that represented by the lower part of the Shasta-Chico series.

The relation which the Comanche series of Texas and Mexico is believed to hold to the Aucella beds of that region and also to the Upper Cretaceous renders it highly probable that it is contemporaneous with a large part of the Shasta-Chico series.

United States Geological Survey,
*Washington, D. C., March 20, 1894.*




A PORTION OF THE COOSA

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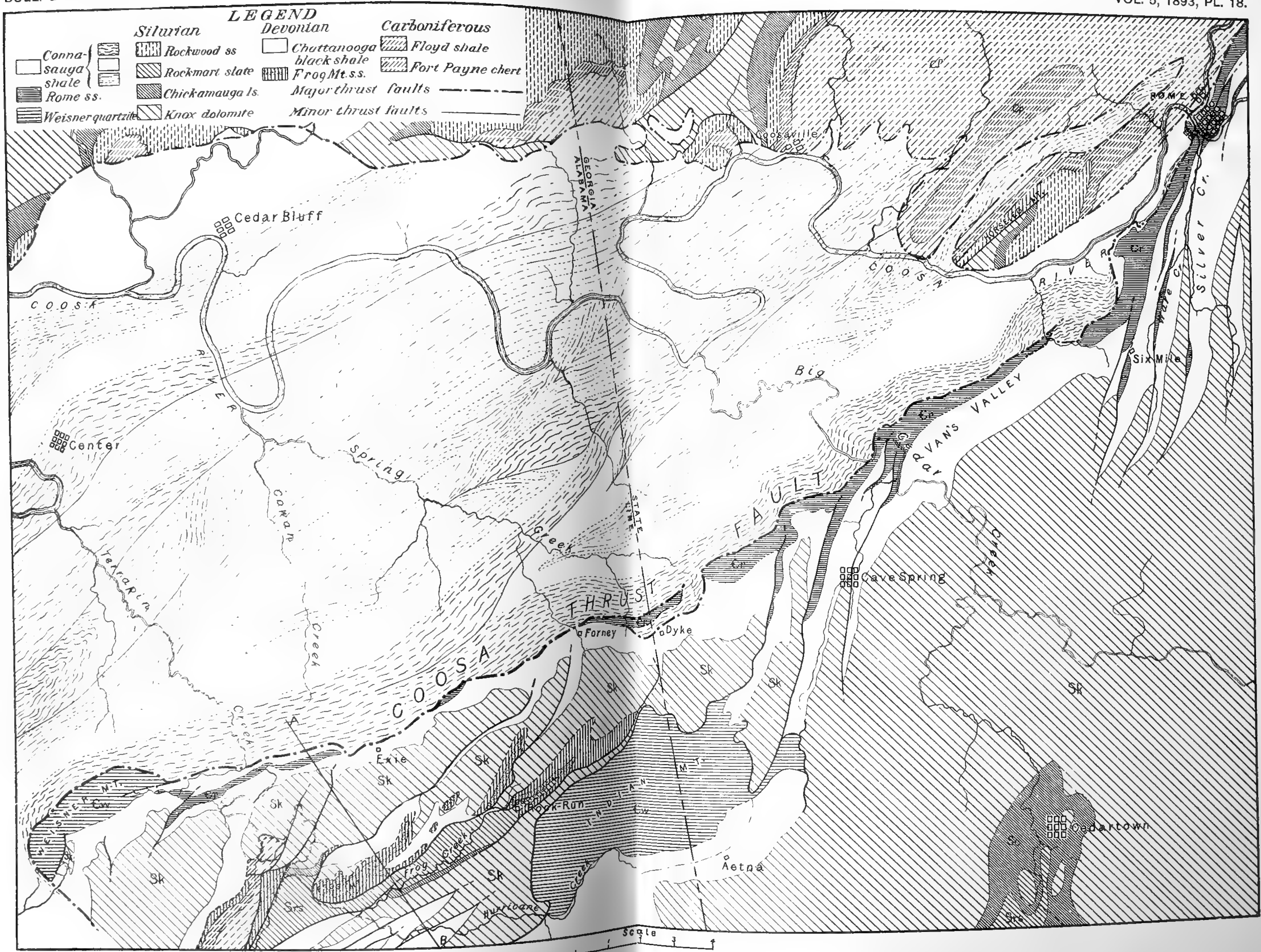


A PORTION OF THE COOSA VALLEY IN GEORGIA AND ALABAMA.

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# GEOLOGY OF A PORTION OF THE COOSA VALLEY IN GEORGIA AND ALABAMA*

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*(Read before the Society December 28, 1893)*

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## INTRODUCTION.

The region discussed in the following paper embraces portions of the Rome and Fort Payne atlas sheets of the United States Geological Survey in Georgia and Alabama. The outlines of its geology have already been presented to this Society in a paper read at the Washington meeting in 1890. While the main features of its structure were known at that time the details had not yet been worked out. Further study of this region during the past summer has cleared up much of the obscurity heretofore surrounding its geologic history, and it is believed the results obtained are of sufficient importance to warrant bringing the subject

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before the Society again; also recent work by Mr Walcott on the paleontology of the region has made possible certain stratigraphic correlations of considerable interest.

## Physiography of the Region.

The accompanying map shows the areal distribution of the formations within the region, and the form of the surface is in large measure dependent on the character of the underlying rocks. From Rome, shown on the northeastern corner of the map, a line of hills extends diagonally across toward the southwestern corner, culminating in Weisner mountain. This line of hills separates the region into distinct physiographic divisions. On the northwest is the Coosa valley, underlain for the most part by soft shales and limestones which have been eroded down to a nearly perfect plain. The level surface is interrupted by a few slight elevations composed of harder shales or protected by a cap of coarse gravel. The Coosa river has an extremely sinuous course, evidently inherited from conditions differing slightly from those which prevail at present. Its channel is sunk 40 to 60 feet below the general level of the valley, and its flood-plain has only a very moderate width.

The southeastern portion of the area represented by the map is underlain by rocks of diverse character, and hence it has a more diversified topography. Adjacent to the dividing line of hills above mentioned is a narrow valley underlain by shales. South of Rome several other narrow valleys diverge from this one and penetrate a few miles within the border of the high rolling land to the eastward. Between Cave spring and Weisner mountain numerous narrow valleys alternate with irregular ridges and hills. The dominant topographic feature of this region is Indian mountain. It consists of several irregular ridges which coalesce to form its highest point and taper off rapidly toward the northeast and southwest.

## Stratigraphy of the Region.

A detailed account of the lithologic character and distribution of the formations of this region will shortly be published with the Rome and Fort Payne atlas sheets, and only such details are included in the present paper as are essential for an understanding of the stratigraphic and structural problems.

*Cambrian Rocks.*—Passing diagonally across the mapped area, from Rome to Weisner mountain, along the northern base of the hills above mentioned, is the intersection of a major thrust-fault plane with the land surface. This has been named the Coosa fault on account of its relation

to the southern border of the Coosa valley. It will be fully described in a subsequent part of this paper, and is mentioned here only because it forms the boundary between two widely different phases of the Cambrian rocks. The formations south of the fault will be first described, then those of the Coosa valley, and finally probable correlations between the two regions will be pointed out.

Three typical sections of the Cambrian rocks south of the Coosa fault will be described briefly:

The first, measured in the vicinity of Rome, shows a gray silicious limestone at the base. This has as yet yielded no fossils, but has been provisionally correlated with the Beaver limestone, which occupies a similar position in the stratigraphic section of east Tennessee, and has been there determined as Lower Cambrian. Above this limestone are from 700 to 1,000 feet of thin-bedded sandstone and sandy shales, with a characteristic bed of white sandstone at the top. These beds constitute the Rome sandstone. Above the sandstone are several hundred feet of olive shales, then beds of oolitic limestone, and finally 1,000 or more feet of calcareous shales, interbedded toward the top with blue limestones.

The second section, measured on Big Cedar creek, shows the Beaver limestone and the Rome sandstone, similar in character and thickness to the same formations in the section at Rome. Here also the lower portion of the Connasauga is composed of fine olive shales, above which are a few beds of oolitic limestone. The upper portion of this formation, however, differs widely in the two sections. The fine calcareous shales of the Rome section are replaced on the Big Cedar by heavy beds of limestone. Some of these beds are gray and crystalline, closely resembling the Knox dolomite, but free from the compact nodular chert of the latter formation. Other beds contain considerable earthy matter which often retains the form of the rock after the calcareous matter has been removed, and also some chert having a characteristic porous structure.

The third section, constructed from numerous measurements in the vicinity of Indian mountain, shows wide differences from the two preceding, especially in its lower portion. The Beaver limestone has not been found here and the Rome sandstone is replaced by a formation of much greater thickness and wholly different in character, the Weisner quartzite. This consists at the base of a heavy bed of quartzitic conglomerate (700 feet), then a great thickness of micaceous shales (1,800 feet), and finally a series of interbedded quartzites, shales and coarse conglomerates (3,000 feet$\pm$). In the upper part of this variable series the shale predominates and the conglomerate occurs as thin lenses. Above this series are greenish silicious shales, having a very considerable though

undetermined thickness. The upper portion of the Indian mountain section closely resembles that on Big Cedar creek. No fossils have yet been found in any member of the Weisner formation, and hence its exact position is not determined, but it probably corresponds to the whole or at least the greater part of the Rome sandstone.

In the early geological study of this region the rocks underlying the Coosa valley were believed to be older than the Rome sandstone and to rest conformably beneath that formation. A study of their fossils, however, has shown them to be of the same age as the Connasauga shale, and hence younger than the Rome; also more careful examination has revealed the presence of the Coosa fault, separating the rocks of the Coosa valley from the Rome sandstone and other formations to the south.

Owing to the extensive deposits of silt and gravel which occur in the Coosa valley, and also to the extremely complicated structure, all attempts at subdivision of these rocks and mapping their distribution must be in a large measure unsatisfactory. In a very general way they may be divided into three groups, although they present so wide variations in lithologic character on opposite sides of the valley that the subdivision is of doubtful value.

The upper division, which generally comes in contact with the Rome sandstone along the Coosa fault, there consists of characteristic greenish silicious shales. In some cases the shale is replaced by greenish micaceous sandstone, which is always highly contorted and crushed into a series of lenticular masses from a fraction of an inch to four or five inches thick. The sandstone is always filled with cracks or fissures which have the appearance of having been produced by contraction of the strata. At the surface these cracks are partially filled with quartz and where they are unweathered the remaining space is occupied by calcite. The sandstone is confined to the southern border of the valley. Passing northward the silicious beds become fewer, being replaced by fine olive-green shales, and throughout the central portion of the valley this division is represented by shales in which occur numerous flat concretions composed of gray silicious material intermediate in character between fine-grained quartzite and chert. As the shale weathers, these concretions accumulate upon the surface, and closely resemble well worn river gravel. Along the northern border of the valley this division becomes very much more calcareous. The concretions are similar in appearance to those above described, but are composed of very silicious limestone.

The intermediate division of the rocks of the Coosa valley is composed of clay shales, but contains in addition varying quantities of limestone. The latter appears in some places as a few thin beds scattered

through the shales and in others as very massive beds, frequently several hundred feet in thickness.

The lowest division consists wholly of fine clay shales, which appear yellow at the surface and dark bluish gray below drainage.

Throughout Coosa valley there is no single stratum sufficiently characteristic as to be recognizable in different exposures and thus used as a datum for correlating other beds. For this reason and for others already mentioned the above classification is simply tentative. It cannot be asserted with any confidence that the divisions represented on the map are made at the same stratigraphic point for any considerable distance, either along the strike or across the outcrops.

When the rocks of the Coosa valley are compared with the Cambrian rocks south of the Coosa fault but little similarity is found. Nothing resembling the upper silicious division occurs in the Rome and Cedar creek sections, and, on the other hand, the characteristic oolitic limestone of these sections is wholly wanting north of the fault. On lithologic grounds alone these rocks would never be correlated. The presence of identical faunas, however, in the two regions affords unmistakable evidence of their contemporaneous deposition. These facts have an important bearing upon the structure of the region, and will be again referred to in connection with the Coosa thrust-fault.

*Silurian Rocks.*—The Knox dolomite probably represents a deposition period covering the upper Cambrian and extending well into the Silurian. The almost complete absence of fossils makes it impossible to fix the limit between the Cambrian and Silurian, and apparently there is no break in the continuity of deposition from bottom to top of the formation. The Knox dolomite has been described by various writers and needs only brief mention in this place. It is probably between three and four thousand feet in thickness, although the nature of its exposures and the fact that it is usually covered with a heavy mantle of residual material render measures of its thickness uncertain.

North of the Coosa valley the Knox dolomite is followed by the Chickamauga, a series of blue, dove-colored and purple limestones; also at a few points south of the Coosa fault the dolomite is overlain by blue limestone, although in the greater part of this region a stratigraphic break, which will be described more fully later, occurs at this point; also south of the fault the purple earthy limestones are replaced by a great thickness of black slates. They have been placed in a separate formation, the Rockmart slate, although they probably represent the same period of deposition as the earthy limestones further north, but it is impracticable to separate the latter from the purer limestones beneath.

North of the valley the Chickamauga limestone is followed without

apparent break by the Rockwood formation, and that by the Carboniferous, Fort Payne chert and Floyd shale. South of the Coosa fault the succession above the Chickamauga is quite different.

*Devonian Rocks.*—A few miles southeast of the region mapped the Rockmart slate is overlain by a thin bed of white quartzose sandstone, and this by fossiliferous chert supposed to correspond to the Fort Payne. In the area mapped no rocks are found which can be shown to rest conformably on the Rockmart slate. As shown upon the map, there are between Indian and Weisner mountains several small areas occupied by a formation which comes in contact with all the older rocks thus far described. It consists of coarse ferruginous sandstone, in some places white, resembling quartzite, and in others yellow or gray and weathering to incoherent beds of sand. Beneath this sandstone and usually deeply covered by its débris are shales, also variable in composition and appearance. No satisfactory measurement has been made of their thickness, but this is probably as variable as their physical appearance.

A number of fossils have been found in these sandstones of Frog mountain. They include *Zaphrentis* sp. (?), *Chætetes complanata* (?), *Spirifera arenosa* (?), *S. arrecta* (?), *Pterinea* sp. (?), *Platyceras* sp. (?), *Orthis musculosa* (?) and *Pentomerus*, cast like that of *P. oblongus conocardium.* Concerning these fossils Mr Walcott says * that "all the specific determinations are uncertain, as the material is not in a satisfactory condition, but the horizon of the Oriskany sandstone is strongly suggested by the general facies of the fauna."

The only formation in the Appalachians south of Tennessee which has hitherto been regarded as Devonian is the Chattanooga black shale, and this is wanting south of the Coosa river. If the Frog mountain sandstone proves to be Oriskany a part of the break between the Silurian and Carboniferous will be filled.

*Unconsolidated Formations.*—Reference has been made to beds of silt and gravel in the Coosa valley which are worthy of some further description. These deposits cover a considerable proportion of the valley, entirely concealing the underlying rocks over many square miles of its surface. They are found at two distinct levels, separated by a vertical interval of about 140 feet. At both levels they rest directly upon a smoothly cut surface of the highly contorted Cambrian shales.

The low-level deposits are most extensive and occur from 30 to 40 feet above the Coosa river. At their base, resting on the erosion surface, are from 1 to 5 feet of gravel and coarse sand showing some indications of bedding. The gravel is coarsest at the bottom, sometimes containing pebbles 6 to 8 inches in diameter. When fresh exposures are examined

* Am. Jour. Sci., vol. xlvii, 1894, p. 237.

the gravel is found to contain a large proportion of chert, in some cases as much as 50 per cent. Next to the chert, schistose quartzite is the most abundant constituent, and after that vein quartz, which makes about 10 per cent. The finer portions of the gravel contain many small fragments of shale and angular or partly rounded fragments of chert, showing clearly that the material has been subjected to only a moderate amount of stream or beach action. This gravel is overlain by from 5 to 15 feet of silt, colored deep red below and yellow or gray at the surface. The line between the gravel and silt is sometimes well defined, but more often the passage is gradual, and occasional pebbles occur several inches or even feet above the base of the silt; also lenses of coarse gravel are sometimes seen in the silt.

The high-level deposits form a cap upon certain isolated hills, which extend from Center, Alabama, northeastward near the middle of the Coosa valley. The composition and arrangement of their materials are almost precisely the same as in the low-level deposits. The gravel is perhaps a little coarser and the overlying silt more deeply colored, but otherwise the deposits are indistinguishable. The intermediate slopes between the upper and lower deposits are quite free from gravel, except the small quantity which has washed down from above, and, so far as can be determined, they are not portions of a single deposit originally spread mantlewise over the entire surface and subsequently removed from the slopes. On the contrary, the high-level deposit appears to be the older, consisting of the remnants of a sheet once continuous over the whole valley and almost entirely removed, together with 140 feet of the underlying shales before the deposition of the low-level deposits.

No opportunity has yet been afforded of tracing these unconsolidated formations to regions in which their age might be determined, and no attempt is here made at their correlation, but it seems probable that further study will show them to be the inland representatives of either the Columbia or Lafayette formations or both.

*Overlaps.*—In studying a region so extensively faulted as that between Indian and Weisner mountains, there is a strong tendency to attribute all unconformities to faulting, and especially is it difficult to discriminate between the broad horizontal thrusts and deposition overlaps. Sufficiently careful mapping, however, renders it possible to determine in most cases to which class an unconformity belongs, even in presence of a heavy residual mantle and deep decay of the rocks.

At least two well-marked erosion overlaps occur in this region. The first is at the top of the Knox dolomite. In the vicinity of Cedartown and immediately southeast of the area covered by the map the contact of the Knox dolomite and Chickamauga limestone is everywhere obscured

by a belt of deep red soil, with which beds of limonite are usually associated. It seems probable that this ferruginous clay represents the deep residual mantle of an old land surface. This is at present, however, only a working hypothesis and requires further field-work to determine its value.

West of the region mapped the evidence of this overlap is more conclusive. It consists in a heavy bed of conglomerate or breccia which occurs at the base of the Chickamauga limestone, and is composed of more or less angular pebbles of Knox dolomite chert imbedded in a calcareous matrix.

The second erosion overlap occurs about the top of the Silurian. It is marked by much more pronounced folding than the earlier one, but is confined to a smaller area. It produces the greatest unconformity in the vicinity of Frog mountain. As shown upon the map, the Frog Mountain sandstone and shale come in contact at different points with the Connasauga shale, Knox dolomite, Chickamauga limestone and Rockmart slate. To bring about this relation by faulting would require a period of folding and erosion followed by the horizontal transfer of younger rocks across the eroded surface of the older. There is no reason why such a process might not take place under proper conditions, but the evidence is against the hypothesis of faulting in this particular case and in favor of the hypothesis of overlap. No rocks are found in this region belonging to the Rockwood (Upper Silurian), while toward the northeast and southwest this formation carries heavy conglomerates, which represent shore conditions of deposition adjacent to a Silurian land area.

The entire absence of the Chattanooga (Devonian) black shale south of the Coosa river indicates a third overlap. The corresponding period of erosion must have covered nearly the whole of the Devonian, but was probably marked by slight elevation, and consequently little degradation, so that the Carboniferous rocks appear to rest conformably upon the Frog Mountain (Lower Devonian) or Rockwood (Upper Silurian) sandstones.

## Geologic Structure of the Region.

The structure of the region between Rome and Weisner mountain is probably as complicated as that of any portion of the Appalachians. Three types of structure, more or less closely related genetically, are here found associated, and the complication is further increased by extensive deposition overlaps and by abrupt lithologic changes. Only the main features of this structure could be presented here, even if all the details had been or could be worked out. For reasons given above all attempts

to unravel the complicated structure of the Coosa valley rocks have proved unavailing, but more satisfactory results have been obtained in the region south of the Coosa fault.

*Folds.*—Probably in this region, as elsewhere in the Appalachians, the first structural forms developed by horizontal compression were the ordinary step-folds. These were doubtless modified by irregularities in the original synclines of deposition, which are indicated by the unconformities and great variations in formation thicknesses. In the less complicated portions of the region these folds remain more or less perfectly preserved, but generally they have been entirely obliterated by subsequent faulting.

Immediately south of Rome several short folds bring the Connasauga shale above baselevel, and consequently give rise to narrow valleys, penetrating southward a few miles within the dolomite area. Each of these folds, however, has been faulted along its western side. A similar faulted anticline extends southward from Cave Spring. The extensive area of dolomite, whose border is penetrated by these narrow anticlines, is a broad, gently undulating syncline pitching southward. Its axis at Cedartown is occupied by the overlying Chickamauga limestone and Rockmart slate. An explanation of this broad area of practically undisturbed rocks adjacent to the intensely faulted region on the west will be suggested below.

In the region west of Cave Spring the folds which probably once existed have been entirely obliterated, excepting a few very irregular synclines in the faulted blocks of dolomite and possibly an anticline in the Rome sandstone west of Exie. So far as their structure can be determined, the Frog Mountain sandstones form closed synclines, but these are secondary structures, developed after the subterranes had already been folded and eroded.

*Minor Thrust-faults.*—The second type of structure is the normal Appalachian thrust-fault, modified by the peculiar conditions prevailing in this region. A great majority of these faults extend nearly due north and south, and hence intersect the main structure axes of the region at angles of 30° or 40°. Immediately south of Rome at least seven of these minor thrusts occur within a belt three miles wide. They vary in length from 3 to 8 miles and overlap along the strike. The strata are thus cut into a number of narrow strips which form monoclinals dipping steeply toward the east. In the vicinity of Cave Spring is another series of faults similar in most respects to those south of Rome.

Between Indian and Weisner mountains there is less regularity in the arrangement of the minor thrusts, and their general trend is somewhat east of north. A strip of Knox dolomite from one to four miles in width

extends from near Cave Spring toward the southwest, lying north of Indian and south of Weisner mountains. This belt of dolomite is intersected by a series of nearly parallel thrust-faults which cut diagonally across, separating it into irregular monoclinal blocks. The faults disappear in the belt of Connasauga shale on the north, while their throw is greatest at the northern edge of the dolomite, decreasing southward, and in some cases disappearing within the dolomite area. These faults give rise to the narrow belts of shale which branch from the northern belt and extend varying distances toward the south, forming narrow valleys among the dolomite hills.

One of these faults, beginning on the state line, turns westward along the northern base of Indian mountain, passing through Rock Run. It is specially interesting on account of its connection with the Rock Run limonite and bauxite deposits.

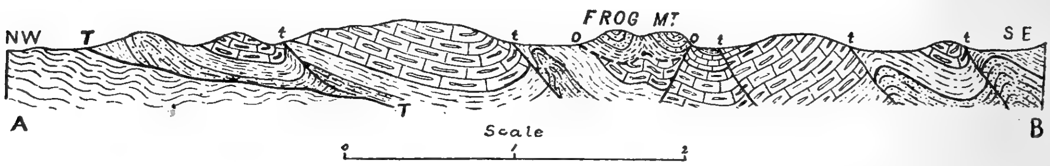


FIGURE 1.—*Section through Frog Mountain, south of the Coosa Valley.*

*T T* = Major thrust-fault; *t t t* = Minor thrust-faults; *O O* = Upper Silurian overlaps.

The fault which begins about two miles southwest of Forney is shown on the map as passing around the southwestern end of Frog mountain and turning back toward the northeast as far as Rock Run, the two portions of the fault being thus approximately parallel. To produce the observed distribution of the formations the two parallel limbs of this fault must hade in opposite directions. The northern limb is precisely similar to the other thrust-faults of this series, the younger rocks are upon its northern side and the fault-plane dips toward the south. The relation of the formations along the southern limb is different. From Hurricane creek to the northeastern end of Frog mountain the rocks on the northern side of the fault are the younger, while from that point to Rock Run they are the older. The latter is the normal relation for a northward dipping fault-plane, as this is believed to be. The abnormal relation along the southern border of Frog mountain is brought about by the presence of the plane of overlap, indicated by *O O* in the structure section, figure 1. The fault branching from the one just described west of Rock Run and extending nearly to Forney is quite distinct and has the normal southeastern hade.

The very marked differences between these folds and faults and those further north in Tennessee and Virginia are due chiefly to the peculiar

stratigraphic conditions of the region. For a long distance north of Indian mountain the Cambrian rocks consist of soft shales and limestones which afford little resistance to folding, while toward the south they contain great masses of conglomerate and quartzite. These massive strata themselves resisted folding and acted as immovable buttresses, against which the less rigid rocks were thrust; hence the effect of great compression was concentrated within a narrow belt west of Indian mountain, while the broad Cedartown syncline lying to the eastward of this buttress was so protected from the compression that its strata remain nearly horizontal. The eastward flow of strata past the northern end of this buttress necessitated a certain amount of rotation in the strata of this region, and this rotation determined the position of the minor thrusts transverse to the main structure lines. The rotation is especially marked in the monoclinal blocks of Knox dolomite between Cave Spring and Weisner mountain, and this also accounts for the group of minor thrusts south of Rome.

*Major Thrust-faults.*—Two or three faults of this type occur within the region under consideration. The most remarkable of these, the Rome thrust-fault, has already been described.* Owing to peculiarly favorable conditions, certain portions of the overthrust rocks have been preserved from erosion and afford unmistakable evidence of horizontal displacement of the strata as well as a minimum measure of its amount.

The second example of this type, the Coosa fault, has been already referred to above. As shown on the accompanying map, it extends from Rome southwestward on the border of the Coosa valley along the northern base of Weisner mountain, turning south and then southeast around its western end. The diversity of formations adjacent to different portions of this fault is very much less than in the case of the Rome fault. Chiefly for this reason it was overlooked in the early study of the region, and until the entire belt was carefully mapped it was regarded as a normal contact between adjacent formations. Upon the northern side of the fault throughout its entire length, with the exception of a mile or two near Rome, occur the green silicious Cambrian sandstone and shale above described. On the southern side of the fault there is not quite so great uniformity. Throughout a little more than half its length the Rome sandstone lies immediately superjacent to the fault plane. Between Rome and Cedar creek a narrow strip of Beaver limestone occurs at intervals beneath the Rome sandstone and next to the fault. From Forney to the eastern end of Weisner mountain the Rome sandstone almost entirely disappears, or if present is not in contact with the fault, being replaced by the Connasauga.

* The Overthrust Faults of the Southern Appalachians: Bull. Geol. Soc. Am., vol. 2, 1891, pp. 141–154.

Although the residual surface material usually conceals the fault plane, artificial cuttings at some points reveal the exact contact between the overthrust and underthrust strata. As stated above, the green silicious shales of the Coosa valley are always highly contorted, but much more so near the fault than elsewhere. The original bedding is sometimes quite obliterated and the rock is in the form of small lenticular masses with slickensided surfaces. The rocks above the fault plane are usually much less disturbed than those below. In all cases where the exact contact could be seen the rocks above the fault plane were the Rome sandstones and their greater rigidity may in a measure account for their less disturbance.

Just south of the Etowah river in Rome the fault plane is well exposed. The rocks are crushed and deeply weathered, but the bedding, so far as it can be determined, is approximately parallel above and below the fault plane. A stratum of obscurely bedded red and yellow clay 8 or 10 feet in thickness marks the plane on which the maximum motion occurred. It contains fragments of the overthrust and underthrust rocks and is evidently a finely comminuted and deeply weathered fault breccia. A large amount of motion has evidently taken place within the strata on both sides of the main thrust plane, and every bedding plane for some distance above and a considerably greater distance below shows sickensiding.

In a roadcut about six miles southwest of Rome the fault plane is shown even more clearly than in the case above described. It dips southeastward about 12°, although in the 20 feet observed the angle varies from 10° to 15°. The thrust-plane is marked by a bed 2 or 3 feet in thickness of reddish clay containing many small angular fragments of the adjacent rocks. Above this fault breccia the sandstone is only slightly disturbed, while below the green silicious shale has almost entirely lost its bedding.

*Relation of minor and major Thrusts.*—It will be seen from the accompanying map that while the minor thrust-faults have a nearly north-and-south trend they do not cross the Coosa fault, but in most cases die out in the band of Cambrian shale and sandstone upon its southeastern side. At two points the Coosa fault appears to be intersected and offset, but in neither case does the intersecting fault belong clearly to the class of minor thrusts above described. It seems scarcely possible that if major and minor thrusts were developed at the same time the latter should not in some cases at least intersect the former; also if the minor thrusts had been developed subsequent to the major thrusts they would have intersected the latter even more frequently; hence it seems a fair inference that the two types of faulting belong to distinct periods of or-

ogenic activity. If these periods were separated by a long time-interval considerable erosion must have taken place. Thus some indication is afforded of the conditions which determined the character of the faulting, and the conclusion reached by other lines of evidence is strengthened, that folding and minor thrust-faulting result from the compression of a competent stratum under great load, while major thrusts result from compression after erosion has removed much of the load from the rigid beds and at the same time developed lines of weakness in them.

*Amount of horizontal Displacement.*—As described in the paper above cited, the thrust-plane of the Rome fault has itself been folded by subsequent compression. By reason of this folding certain portions of the overthrust rocks which rest in the synclines have been preserved from erosion and afford a minimum measure of horizontal displacement. If such subsequent folding has taken place in the case of the Coosa fault, the resulting folds have either not yet been revealed by erosion or they have been entirely removed. The latter is the more probable. Excepting the two small offsets, evidently produced by intersecting faults, the course of the Coosa fault is remarkably direct, considering the low inclination of the thrust-plane; but it is quite probable that if the surface of this region were degraded only a few hundred feet further the outcrop of the Rome fault-plane, now so remarkably sinuous, would be equally as direct as that of the Coosa fault, and the latter may have had at some earlier stage of erosion a course equally as sinuous as the former has at the present time.

The strongest evidence of great horizontal displacement on the Coosa thrust-plane is found in the widely diverse character of contemporaneous formations on its opposite sides. It will be recalled that the same faunas are found in the Connasauga shale and in the formations underlying the Coosa valley, but the rocks which contain these fossils differ widely in appearance and point to very different conditions of deposition. Two explanations of these facts are suggested: First, there may have been a barrier of land between the two areas of deposition, so that the rocks of the Coosa valley and those south of the Coosa fault were laid down in separate, though contiguous, basins. Deriving their sediments from different sources, they would differ in lithologic character, while the faunas would be essentially the same. No trace of such a land barrier, however, has yet been found, and the rocks in question contain none of the characteristic marks of littoral deposition.

The second explanation of the above facts is that the rocks now occupying adjacent areas at the surface were originally deposited in comparatively remote parts of the same sea, and that the observed lithologic differences are due to the gradual change which is always found to occur

when the same beds are traced for a considerable distance. The contrast in character is greatly heightened, since all the intermediate varieties are wanting and the most different types are brought into immediate contact, where comparison reveals differences which in their normal relation would entirely escape notice. The visible displacement on the Rome fault is about 4½ miles. Upon a very moderate estimate of subsequent folding and erosion, the original displacement must have been at least twice, and was more probably three times, that amount. If an equal displacement has occurred on the Coosa fault-plane, the original 10 or 15 miles of interval between rocks now adjacent would easily account for these observed lithologic differences.

## Paleozoic History of the Region.

From the facts detailed above a tolerably definite idea may be obtained of the history through which this region has passed. It begins in Cambrian time, when the land lay to the southeast and a broad expanse of sea stretched far to the west and northwest. The rivers brought down sediments from the crystalline rocks on the east. At first, while the land was high, coarse sand was deposited in great lenses about the river mouths, and as the land was worn down the sediments became finer, till at the close of the Connasauga epoch only the finest mud was deposited. Then followed a long period of calcareous precipitation, with conditions, not clearly understood, favoring the deposition of amorphous silica as chert or flint. This was the Knox dolomite epoch, covering late Cambrian and early Silurian time. Following this was an uplift with gentle folding which brought portions of the region above sealevel. Probably most of the area covered by the map was dry land undergoing subaërial degradation, with the formation of a deep residual mantle and the deposition about its border of conglomerates composed of the indurated portions of the eroded rocks. Following this comparatively short period of uplift was a much longer one, during which the sea covered the region and the Chickamauga limestone was deposited. After a few hundred feet of blue limestone had formed changes occurred in the altitude of the land toward the southeast, so that fine mechanical sediments replaced pure limestone, and a great thickness of calcareous clay shales, now the Rockmart slate, was laid down. This long period of quiet deposition was terminated by a period of disturbance similar to the one which brought the Knox dolomite epoch to an end, but the folding was very much more profound in the second than in the first. Within the area mapped, and extending some distance toward the southeast, rather sharp folds were produced, trending nearly north and south.

The folding was accompanied and followed by erosion, which probably reduced the rising land nearly or quite to sealevel. This period of erosion extended over the latter part of the Silurian, but early in the Devonian the region was again invaded by the sea, and across the truncated edges of the folded strata coarse sands were deposited which now form the Frog Mountain sandstones. The region may have been above sealevel again during the latter part of the Devonian, but if elevation occurred at that time it was accompanied by so little folding that practically no erosion took place, and the overlap is indicated only by the absence of Upper Devonian formations and not by any appreciable unconformability of strata. During early Carboniferous time the region was again covered by the sea and a continuous layer of cherty limestone deposited over its entire extent.

The orogenic activity which had manifested itself at intervals during most of Paleozoic time culminated in the great Appalachian revolution probably near the close of the Carboniferous. Considering the entire Appalachian province as a unit, the activity may have been continuous, although in any particular region it apparently consisted of several periods of activity separated by intervals of comparative quiet. During the early part of this complex series of movements in the region under consideration the horizontal compression found relief in the formation, first, of simple folds, and then of the minor thrusts. Finally, after a comparatively long period of erosion, the strata thus folded and faulted were displaced upon nearly horizontal planes, producing the major thrust-faults above described.

## Post-Paleozoic History of the Region.

The history sketched above is recorded in the rocks of the region and their underground structure. The post-Paleozoic history, on the other hand, is recorded chiefly in its physiography; in the forms of surface relief and drainage. The accompanying map represents too small an area for the deciphering of this later history, which has been made out from a study of the entire Appalachian province.*

Evidence has elsewhere been found of two prolonged periods of baseleveling which resulted in the formation of extensive peneplains. The first or Cretaceous peneplain was most perfectly developed, but has been to a considerable extent destroyed by subsequent erosion. In the area mapped the few remnants of this plain have an altitude of 1,300 feet. They are found in the crests of the subordinate ridges forming Indian

* The Geomorphology of the Southern Appalachians, by C. Willard Hayes and Marius R. Campbell. Nat. Geog. Mag., vol. vi, 1894.

and Weisner mountains, while the main summits of those mountains were not reduced quite to the level of the Cretaceous peneplain.

The second or Tertiary peneplain was developed only on areas of comparatively soft rocks, but has been more perfectly preserved, so that considerable remnants are found in the region mapped. This peneplain, like the preceding, was warped as it was elevated, and now slopes gently toward the northwest, decreasing in altitude from more than 900 feet in the vicinity of Cedartown to about 750 at the Coosa river. The broad dolomite area between Rome and Cedartown was nearly reduced to base-level, though the more silicious portions remained as low hills from 100 to 150 feet above the peneplain.

During the closing epoch of the Tertiary, erosion was active upon the surface of this peneplain, and the Coosa valley was lowered about 140 feet on the underlying soft shales, only a few low hills, as the one on which Center is located, escaping degradation. Following the formation both of the Tertiary peneplain and the subsequent baseleveled valley came a slight depression of the surface probably nearly or quite to sea-level. At the same time the carrying capacity of the upper portion of the streams was increased either by steeper slope or greater volume, so that they brought down vast quantities of gravel which they deposited along their slackened lower courses. These are the high and low-level deposits of silt and gravel already described.

Finally, the region has very recently been slightly elevated, and the Coosa river is at present lowering its channel in the last formed baselevel valley. Its sinuous course is inherited directly from the conditions which prevailed during the deposition of the low-level gravels when the stream was overloaded and wandered from side to side of a broad deposition plain.

United States Geological Survey,
*Washington, D. C., April 9, 1894.*

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# MICA DEPOSITS IN THE LAURENTIAN OF THE OTTAWA DISTRICT

BY R. W. ELLS

(*Presented before the Society December 28, 1893*)

CONTENTS



## INTRODUCTORY.

Recent investigations upon the Laurentian rocks which have such an enormous development in Canada have shown that the views formerly held as to their structure and origin must to a large extent be modified. This change of views applies with equal force to the theories at one time put forth to account for the presence of certain economic minerals for which these rocks have long been celebrated.

## ROCK GROUPS OF THE REGION.

*Metamorphosed Sedimentaries.*—From the composition, structural arrangement and general relations of large portions of that great rock system, it appears that certain beds found therein present many of the features peculiar to deposits originally sedimentary, and that these beds

through extreme processes of metamorphism have been changed from their original condition of limestone, sandstone and possibly shale into marble, quartzite, slate and gneiss. Many of these beds are regularly interstratified, and this peculiarity can be readily seen in that portion styled by Logan "the Grenville series." In many places throughout the area occupied by these rocks a regular and gradual passage is traceable upward from the silicious into the calcareous beds, as pointed out in my paper on the Laurentian read before this Society last year.

*Intrusives.*—There are, however, great rock masses throughout the system which present very different aspects from the strata just mentioned, not only in their macroscopic and microscopic characters but in their relations to the stratified portions as well, and as has been very clearly pointed out by the observers in the more western areas, these masses, often of large extent, are clearly intrusive, and consequently of more recent date than the presumably sedimentary portion with which they are associated.

This peculiarity of intrusion is not confined to any particular area, but is as readily recognized in the district north of the Ottawa river as in the country north of lakes Superior and Huron, or further east along the shores of Labrador, though over some areas the intrusive masses have a much greater extent than in others.

*Former Errors in Identification.*—The intrusive character of some of these rocks was clearly recognized by Sir William Logan and other early workers in this difficult field. Certain other masses, however, more particularly associated with the development of the economic minerals, such as mica, apatite, graphite, etcetera, were held to be of sedimentary origin. These included most of the pyroxenic rocks, the quartz-felspars and certain of the syenites, together with the anorthosites, in many of which a certain gneissic structure is developed through the agencies which have produced the general metamorphism of the system. Hence many of the mineral deposits which occur in these intrusives were supposed to occur as beds and to have their origin in the same causes which tended to develop veins of mineral matter in what were known to be true sedimentary rocks. The confusion of gneissic sedimentary with volcanic rocks and the placing of them in the same group were very natural errors, and the metamorphic origin of many of the granites and syenites is still maintained by many earnest workers on the subject. This view applies not only to those masses found in the Laurentian, but to others occurring in Quebec, New Brunswick and Nova Scotia, which have generally been regarded as of the age of the Devonian or the close of the Upper Silurian, and in which a gneissic structure—a structure clearly induced by pressure—is also frequently developed, more particu-

larly along the margins of the outcrops. In the same way also great areas of greenstone or dioritic rocks found in the Huronian system at various places have at some time assumed the character of chloritic schists.

The periods of folding and crumpling by which these changes of structure were produced varied in different localities. Thus, in the Laurentian area the plications resulted from agencies which acted prior to the deposition of the Potsdam sandstone, since this formation flanks the Laurentian rocks in a horizontal position and even occurs in a few scattered outcrops at points in the area itself. It is probable also that many of the present mineral-bearing veins or dikes were developed at this time, while in the case of the dioritic and syenitic rocks of the Eastern Townships this folding, schistosity and overturning were subsequent to the Upper Silurian time, since fossiliferous strata of that age were involved in the crumpling to such an extent as not only to impart a truly schistose structure to the fossiliferous slates themselves, but in places to overturn them so completely as to place them directly beneath the slates of the Cambro-Silurian system.

Thus it will be seen that the hypothesis which assumed that the greater portion of these intrusive gneissic and foliated portions of the system, though in places this foliation is lacking, was an integral portion of the sedimentary series, was a natural one, more especially when we find that many of the smaller dikes or bands of pyroxene, anorthosite and felspar have been intruded along the bedding-planes of the gneiss; and hence we find the deposits of mica, apatite, etcetera, frequently described as bedded developments of these minerals, on the ground that the pyroxene rock was also sedimentary, while the occurrence of apatite-bearing bands in certain places, in unconformable relation to the sedimentary gneiss, led to the supposition that certain of these deposits were vein-masses rather than beds.

## MINERALS.

*Rock Relations determined by Minerals.*—The many openings which have been made in the apatite and mica deposits of the Gatineau and Lièvre districts, for these minerals must to a certain extent be studied together, have facilitated the elucidation of this problem very considerably, and the relations of the associated or containing rocks can now be made out with far greater exactness than in the days before the great value of their mineral contents was discovered. Thus we find that while the strike of the gneiss and limestones, extending over many thousands of square miles, is very uniformly north to north 15° east, unless this has been deflected by

local causes, easily recognized, the strike of the pyroxene, quartz-felspar, and other dike-like intrusions, is often nearly at right angles to this, but sometimes varying from it to apparent conformity with the bedding of the stratified rocks. The dip of the gneiss changes frequently from the east to the west, so that over a section of hundreds of miles in extent the whole series is found to be in a succession of folds, often closely placed with regularly occurring anticlinals and synclinals, which structure is, moreover, wonderfully confused by the occurrence of numerous faults and overturns.

*Occurrence of Apatite and Mica.*—It has been already pointed out in a previous paper * that the deposits of apatite are confined entirely to the pyroxene dikes of this system, and that the mineral occurs for the most part near the contact of these dikes with the gneiss or near the intersection of cross-dikes of intrusive dolerite or felspar. The occurrence of mica in these rocks presents almost identically similar conditions to the apatite as regards its presence in workable quantity, but differs in this respect, that while the apatite is found exclusively in pyroxenic rocks, the mica is often associated with other kinds of intrusives. It is, however, more particularly found in two varieties, namely, the pyroxene which varies greatly in color and hardness, and in a coarse admixture of clear quartz and grayish felspar, which is generally styled a pegmatite, and which contains also crystals of tourmaline, garnet, etcetera. This quartz-felspar rock differs, however, very greatly from the usual varieties of pegmatite found in the Laurentian, which is usually very much finer-grained, and occurs generally as veins intersecting the gneiss as one approaches the great masses of anorthosite or gabbro. The quartz-felspar those of pyroxene, frequently cut the gneiss along the line of strike of dikes, like the latter, but its intrusive character is clearly evidenced in most cases by the sending off of spurs into the mass of the gneiss in contact, as well as by the fact that it frequently cuts directly across the gneiss and intersects the pyroxene as well, thus showing it to be a later intrusion. Inclusions of the grayish or reddish gneiss which is penetrated by these rocks are also frequently found caught in the mass, both of the pyroxene andfel spar, and furnish further evidence of the intrusive character of these rocks. In some places the presence of three distinctly intrusive dikes is recognized in the same opening, the oldest being the pyroxene, the second, cutting the pyroxene, is a quartz-felspar, and the third is a black trappean rock.

It has been stated by some writers that the apatite and mica occur in the Laurentian limestone, as well as in the gneiss and pyroxene. This

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* Canadian Mining Review, Ottawa, March, 1893.

view has doubtless arisen from an imperfect study of both the limestones and pyroxene, the latter in the earlier stage of the investigations on these rocks being regarded as a peculiar variety of the sedimentary gneiss formation, as already pointed out, while concerning the former it is found that in many of the pyroxene dikes, more particularly near their contact with the grayish gneiss, an irregular development of calcite, generally of pink color, occurs, which by the miners is styled a limestone, and has thence been confounded with the distinctly different limestone formation which forms the upper portion of the Laurentian system. In no case can this calcite, in which very frequently the mica crystals, as well as crystals of apatite, are disseminated, be regarded as a member of the sedimentary or stratified Laurentian series, but is always found as an irregular, generally pockety, mass in the intrusive pyroxene.

*Mica-Apatite Horizon.*—The horizon of these deposits, both of mica and apatite, can now be very clearly defined. They are for the most part confined to the series of gneisses which constitute the upper portion of the Laurentian silicious rocks and which underlie the limestone proper. These gneisses are generally of some shade of grey, with reddish grey, reddish and hornblendic bands, some of which are garnetiferous, and nearly all of which contain a large percentage of silica in the form of quartz. These beds, as already pointed out, graduate upward by regular passage through the interstratification of calcareous layers into the massive crystalline limestone formation. In the Buckingham and Templeton areas apatite and mica are rarely found in dikes cutting calcareous strata, but in the Gatineau area several localities are known where large dikes of pyroxene in limestone carry mica in workable quantity.

Mica deposits generally occur in the form of crystals, some of which reach an enormous size, instances being lately reported of single crystals measuring nearly eight feet across the face. These crystals sometimes occur in the pyroxene in pockety masses distinct from each other, or in somewhat irregular deposits near the contact of the enclosing pyroxene and the gneiss adjacent or as scattered crystals through the mass of the dike itself, but generally near the contact. In many cases of pyroxene dikes where the mica occurs as a contact deposit near the gneiss it is found associated with masses of pink calcite, some of which are but of small extent, while others have a thickness of several feet and are traceable for some yards. The mica found in the calcite is, as a rule, in well formed crystals disseminated through the mass, and often associated with well terminated crystals of apatite. In some cases the latter penetrate the former, while frequently inclusions of calcite or apatite are found in the center of the mica crystal. Of the mica found in the mass of the pyroxene it may be said that the crystalline structure is rarely perfect.

*Mode of Occurrence of the Micas.*—From recent observations it may be stated that the merchantable micas of the district occur under six principal conditions, thus:

1. In pyroxene intrusive rocks which either cut directly across the strike of greyish or other colored gneisses or are intruded along the line of stratification. Some of these deposits have been worked downward along the contact with the gneiss, where the mica is most generally found, for 250 feet, as at the Lake Girard mine, and irregular masses of pink calcite are abundant. In certain places apatite crystals occur associated with the mica, but at other times these are apparently wanting. As in the case of apatite deposits, mica occurring in this condition would apparently be found at almost any workable depth.

2. In pyroxene rocks near the contact of cross-dikes of diorite or felspar, the action of which on the pyroxene has led to the formation of both mica and apatite. Numerous instances of this mode of occurrence are found, both in the mines of apatite and mica, the deposits of the latter in certain areas being quite extensive and the crystals of large size.

3. In pyroxene rock itself, distinct from the contact with the gneiss. In these cases the mica crystals, often of large size but frequently crushed or broken, apparently follow certain lines of faults or fracture. Some of these deposits can be traced for several yards, but for the most part are pockety. Some of these pyroxene masses are very extensive, as in the case of the Cascade mine on the Gatineau river and elsewhere in the vicinity. In these cases calcite is rarely seen and apatite is almost entirely absent. When cut by cross-dikes conditions for the occurrence of mica or apatite should be very favorable.

4. Dikes of pyroxene, often large, cutting limestone through which subsequent dikes of diorite or felspar have intruded as in Hincks township. The crystals occurring in the pyroxene near to the felspar dikes are often of large size and of dark color, resembling in this respect a biotite mica.

The mica found under the conditions stated above in one, two, three and four is all amber-colored and of the variety known as phlogopite or magnesia mica.

5. In felspathic-quartzose rocks which constitute dikes often of very large size, cutting red and greyish gneiss, as at Villeneuve and Venosta. These are distinct from the smaller veins of pegmatite which occur frequently in the gneiss as the anorthosite areas are approached. In this case the mica is muscovite or potash mica and is invariably found in that portion of the dike near the contact with the gneiss. The crystals frequently are of large size and white in color, associated with crystals of tourmaline, garnet, etcetera, but with no apatite, unless pyroxene is also present.

6th. In quartz-felspar dikes cutting crystalline limestone, in which case the crystals are generally of small size, mostly of dark color and of but little value.

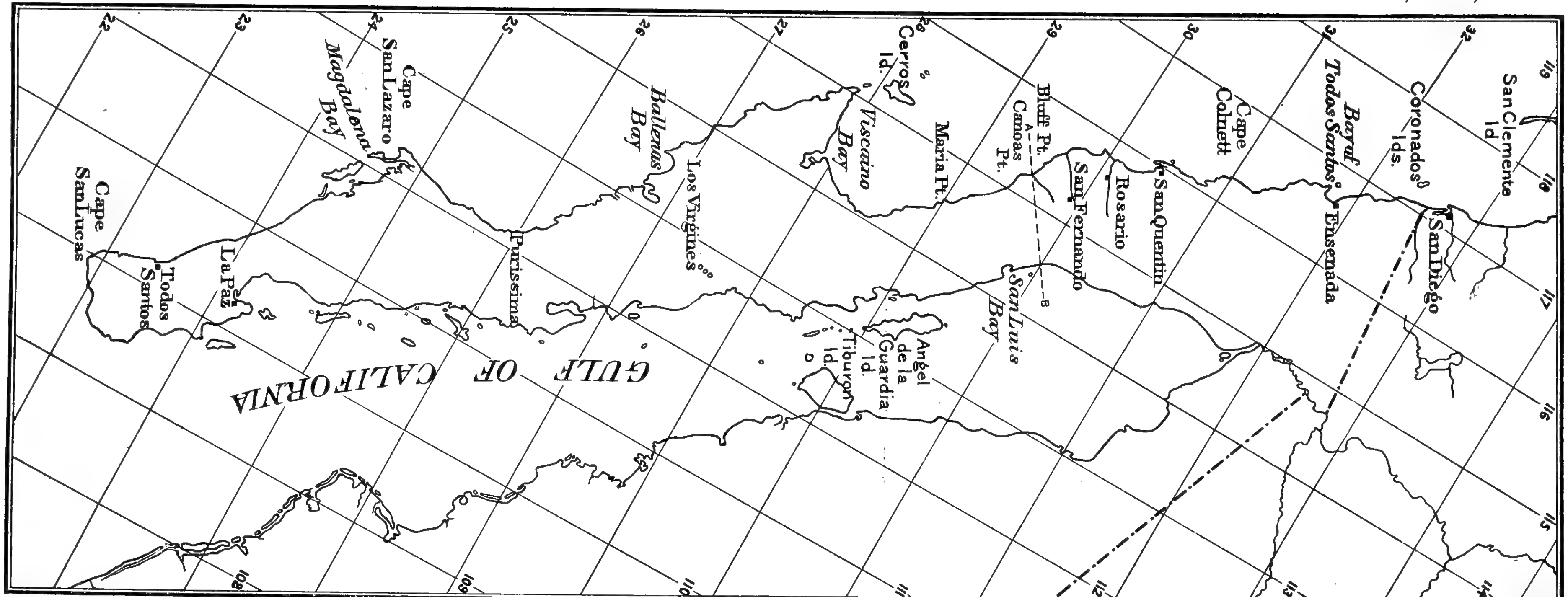
In the case of the amber micas this peculiarity was noted that when the pyroxene was of a light shade of green or greenish gray and comparatively soft, the mica was correspondingly light colored and clear, and in some places almost approached the muscovite in general appearance. As the pyroxene became darker in color and harder in texture, the mica assumed a correspondingly darker tint and a brittle or harder character, and in certain cases where dikes of blackish hornblendic diorite were present the mica also assumes a black color as well.

*Differences observable in the Mica-Apatite Deposits.*—There is one feature observed in the deposits of mica and apatite which is not yet explainable from the study of the rocks in the field. Thus in the apatite mines along the Lièvre river while the deposits of that mineral are sometimes very extensive and can be traced downward for hundreds of feet, as proved by the workings of the North Star and the High Rock mines, the occurrence of mica in quantity with the apatite is rare, though in certain areas both are present. In the Templeton or McGregor Lake belt of apatite mines the two minerals frequently occur together, in quantity sufficient to be profitably worked in both cases. Thus at the Blackburn and Jackson Rae mines, the former especially long celebrated for its great yield of apatite, the mica also occurs in considerable quantity and in crystals of large size and good quality. In both the Lièvre and Templeton areas the apatite is rarely found in crystals, occurring for the most part in pockety bunches which vary in size from insignificant deposits to masses of a thousand tons.

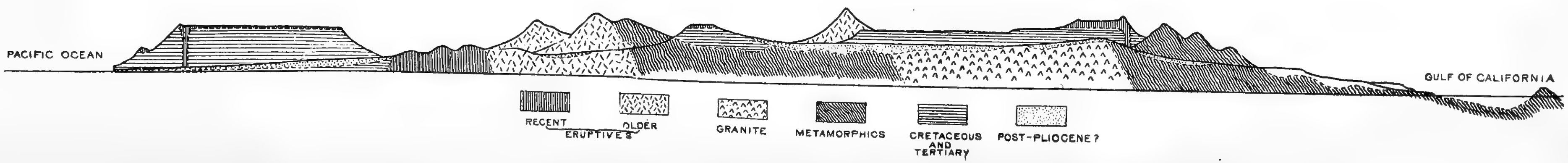
In the Gatineau area the quantity of pink calcite in the pyroxene becomes much greater. There is very often an admixture of mica and apatite crystals, the latter in quantity sometimes sufficient to be worken profitably, while in other areas the mica occurs without the apatite or with the latter only in very limited development. Very often quantities of beautiful crystals of pyroxene, sphene and zircon, occur in in these deposits with the mica. Of the apatite associated with the mica in the Gatineau belt it may be said that it presents generally features distinct from that occurring on the Lièvre. The reasons for these different modes of occurrence and association are not, as already remarked, very clear, unless it be due to some feature depending upon the stratigraphical relations of the containing beds or some peculiarities regarding their exact horizon. The difference in the character of the micas themselves is presumably due to the difference in composition of the containing rocks.

*Mica Localities.*—As regards the portions of the Laurentian from which mica may be obtained, it may be said that its occurrence in economic quantities is now known at certain points over a very extended area. Thus in Ontario the mines of Burgess and the adjacent townships yield large quantities, generally of the phlogopite variety. Along the Ottawa river it is found from a point nearly 100 miles west of Ottawa to the township of Grenville, 60 miles east of that city, while on the Gatineau river, which flows into the Ottawa at the city of Ottawa, mines have been located and worked for 80 miles north from its mouth, and the mineral is reported from points many miles further north along that stream. To the east of Quebec it is known on the branch of the Saguenay called the Manouan and in the townships of Escoumains, Bergeronnes and Tadoussac, situated east of the mouth of that river, as well as at several other places along the river Saint Lawrence. The mica found in this district is chiefly muscovite.

The principal areas where this mineral is at present worked are in the belt which extends from North Burgess, in the province of Ontario, approximately along the strike of the gneiss, into the territory adjacent to the Gatineau and Lièvre. Over much of this area south of the Ottawa river the Laurentian is concealed by the mantle of Cambro-Silurian rocks belonging to the Ottawa River basin, but it may be said that the geologic conditions and the stratigraphic sequence in the area south of the Ottawa and in the rear of Kingston are the same as those found in the mineral-bearing belts north of the Ottawa, and that the most favorable conditions under which the deposits of mica and apatite may be looked for occur in those areas occupied by the upper portion of the Laurentian, where traces of igneous agency are visible in the presence of dikes of pyroxene and quartz-felspar, though it should be stated that the mere occurrence of these in the gneiss does not warrant the presence of either of these minerals.




SECTION ON LINE A–B., LATITUDE 30°




MAP AND GEOLOGIC SECTION OF LOWER CALIFORNIA.

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# GEOLOGICAL SKETCH OF LOWER CALIFORNIA

BY S. F. EMMONS AND G. P. MERRILL

(*Presented before the Society December 29, 1893*)

CONTENTS



## INTRODUCTORY.

So little is accurately known with regard either to the topography or the geology of the peninsula of Lower California that it seems desirable to put on record whatever new facts may be learned concerning either, even though derived, as in the present instance, from observations made during hasty trips into its interior for other than strictly geological purposes.

Of the topography of the peninsula the only reliable data published are found on the charts of the United States Hydrographic Office (the Narragansett, 1873–'75, for both coasts, and the Ranger, 1887, for the west coast), which give the immediate coastline and topographical sketches of the adjoining country for a few miles inland.* The few maps of the interior, whether published or in manuscript, that have been consulted show so much discrepancy with one another and with actual natural conditions, where comparison has been possible, that but little reliance

* The map given on plate 19 is copied from the best reduction made by the United States Coast and Geodetic Survey, and though its scale is too small to show details, it serves to express the general outlines of the coast and show the location of the various points mentioned.

can be placed upon them. Our knowledge of the topographical structure is mainly based on the descriptions of the few intelligent travellers who have traversed various parts of the peninsula.

The only important publications with regard to the geology of Lower California are:

1. That of W. H. Gabb,* paleontologist of the California Geological Survey, who in 1867 traversed the entire peninsula from cape Saint Lucas to San Diego on muleback, crossing it ten times during the trip.

2. That of W. Lindgren,† who in June, 1888, spent a few weeks in the vicinity of Todos Santos bay (Ensenada) and the mountains to the east of it.

Some geological notes are also found in the reports of the Mexican boundary and Pacific railroad surveys, the latter by W. P. Blake. Reports on mines in the southern part of the peninsula sometimes contain geological data, but they are rarely accessible, and at best have seldom more than a local bearing.

The original observations on which the present paper‡ is founded were made by Mr Merrill during a fortnight's trip, in July, 1892, from San Quentin on the west coast, in latitude 30° 30′, to the deposits of Mexican onyx, about 150 miles distant, a little south of latitude 30 and near the eastern or Gulf coast; and by Mr Emmons during a stay of somewhat longer duration, mainly at the property of the New Pedrara Onyx Company above mentioned, including overland trips thither from San Quentin, and from the quarries across the peninsula to the west coast between Bluff and Canoas points, in latitude 29° 30′.

Since that time there have appeared papers by Mr H. W. Fairbanks § and Professor A. C. Lawson|| upon the geology of southern California which contain facts that have an important bearing upon the structure of the adjoining peninsula.

## Physical Structure.

The peninsula of Baja California is a narrow strip of broken mountainous land extending roughly from 22° 50′ to 32° 30′ north latitude, about 775 miles long and from 35 to 70 miles in width, with a general northwest and southeast trend parallel to the larger orographic features

* J. Ross Brown: Min. Res. of the U. S. for 1867, Wash., 1868, p. 630.

† W. Lindgren: "Notes on the Geology of Baja California-Mexico." Proc. Cal Acad. Sci., 2d ser., vol, i, 1888, p. 173. Ibid., vol. ii, January, 1889, p. 1. Ibid., vol. iii, April, 1890, p. 26.

‡ In this paper the petrographical determinations were made by Mr Merrill. Mr Emmons is alone responsible for the general structural deductions, in determining which he has made free use of Mr Merrill's field-notes.

§ "The validity of the so-called Wallala beds as a division of the California Cretaceous." Am. Jour. Sci., vol. xlv, June, 1893, p. 473.

|| "The Post-Pliocene Diastrophism of the Coast of Southern California." Bull. Univ. Cal., vol. i, no. 4, December, 1893, p. 115.

of the Pacific slope. Its coast outline, characterized as it is at many points by long sweeps of reëntering curves, with outlying islands and projecting points partly enclosing oval, valley-like basins, is at once suggestive of a partially submerged series of mountain chains.

The peninsula is divided by Gabb into three geographical provinces: A *southern*, extending from cape Saint Lucas to beyond La Paz, characterized by irregular granite mountain chains up to 5,000 feet in height, and with deep valleys containing considerable fertile arable land; an *intermediate* desert region, characterized by tablelands and flat topped ridges, with a considerable extent of interior valleys, and with isolated mountain tops and ranges projecting above the general mesa level, which rarely reach an elevation of more than 3,000 to 4,000 feet; this region has no running water and springs are very scarce; a high *northern* portion from 5,000 to 10,000 feet above sealevel, forming a southern continuation of the mountain region of southern California, which has a number of running streams and large valleys susceptible of cultivation, while the higher portions contain considerable extents of pine forests.

The limits of these three provinces are not sharply defined, but may be taken at about 200 miles in longitudinal extent for the northern, 450 miles for the intermediate desert region, and 100 miles for the southern.

North of the national boundary, in the latitude of San Diego, Lawson recognizes three physiographic provinces: (1) the central mountainous range of the peninsular Sierra, (2) the Colorado desert on the east, and (3) the coastal slope on the west, locally known as the "Mesa."

The Mesa is a terraced plain, sloping gently upward from the coast eastward and extending 12 to 18 miles into the interior, which surrounds some of the outlying points of the central Sierra that project above it. Toward the desert, on the other hand, the mountains present an abrupt escarpment to the east, and the desert plain is in places depressed below sealevel. This escarpment, as Lindgren remarks, lies nearly in a south-southeast line with the eastern face of the Sierra Nevada, with which its general topographical form, as well as its geological structure, more closely allies it than with the Coast range.

While, therefore, from a first glance at existing maps it might appear that the depressions of the Mohave and Colorado deserts and of the Gulf of California were the normal southern extensions of the great depression of the San Joaquin and Sacramento valleys, and that the Peninsular range was therefore the normal southern continuation of the Coast range, there is some reason to be found in its topographical form, and still more, as will be seen later, in its geological structure, for the assumption that the peninsula more properly represents the southern extension of the Sierra Nevada uplift. On this assumption the connection between the

two would be afforded by the various *en echelon* ranges known as the San Jacinto mountains, San Bernardino mountains, etcetera, lying to the northward, while the southern extension of the Coast range proper, cut off by the reëntering angle of the coast between Santa Barbara and Los Angeles, would be represented by the chain of islands, Santa Catalina, San Clemente, etcetera, generally known as the Channel islands, lying off the coast between Los Angeles and San Diego.

To the south of San Diego the mountains come down to the sea and the mesa disappears, being only represented by an occasional patch of later beds which have escaped erosion, as at Sausal and Todos Santos, 60 miles south of the boundary. At Cape Colnett, in latitude 31°, a strip of mesa again forms the immediate coast and widens southward toward San Quentin, in latitude 30° 30′, which is assumed to be about the limit of the northern or mountainous province. From San Quentin southward, as far as examined by the writers, the mesa structure is characteristic of the Pacific coast, the tablelands rising to a height of one to two thousand feet at comparatively short distances from the sea and presenting bold bluffs of soft horizontally stratified beds, often capped by lava flows, which are evidently wearing away rapidly under the erosive action of the waves.

Lindgren, as a result of his observations in the vicinity of Ensenada de Todos Santos, divides the topographic features of the peninsular Sierra into three sections:

1. *The Coast range,* or the first orographic block, rising gradually from the sea to an elevation 3,000 feet in a distance of 20 to 30 miles. Surmounting this are several minor ranges and sharp peaks attaining an elevation of 3,000 to 4,000 feet. A rapid descent leads from the divide of the Coast range to—

2. *The Interior valleys,* an interrupted series of depressions in the middle of the chain at an elevation of 1,800 to 2,000 feet.

3. *The eastern range,* or second orographic block, rising rapidly from the valleys and continuing as an almost level plateau, with a gentle slope up to the peninsular divide and an abrupt, almost precipitous, descent to the desert. The elevation of this remarkable plateau is from 4,000 to 5,000 feet.

This plateau region, which supports a considerable growth of pine forest, extends, according to the meager accounts obtainable, from the boundary southward about to latitude 31°, reaching its culminating point in the high mountain mass now known as San Pedro de Martis, which is apparently the same as the snow-capped mountain called in the Narragansett report "Calamahue" or Santa Catalina (Caterina) mountain.

The area examined by the present writers, which extends 15 to 30 minutes north and south of the 30th parallel of latitude, is separated by

a considerable gap of unknown country from that described by Lindgren. In this latitude the average elevation of the peninsula is about 2,000 feet, and that of its higher ridges may be taken at less than 3,500 feet. It is a singularly arid region, having practically no running water on the surface and very few permanent springs; nevertheless our experience has shown that properly located wells obtain a fair supply of water at depths of 20 to 60 feet. The climate is remarkably equable and healthful, being but little warmer than that of the coast region of southern California and as a rule much drier. The diurnal changes of temperature are, however, very great. It is swept by continuous breezes from either coast, which appear to blow alternately about three days at a time, those from the Pacific being laden with more or less moisture, while the east winds are extremely dry. Like California, it has a rainy season in the spring, but this is generally but of few days' duration and extremely irregular and uncertain.

The most striking feature to the traveller from the north is its peculiar vegetation, which presents but few familiar species among a wilderness of strange and weird forms. It consists mainly of thorny shrubs and flowering plants, the few known representatives of which are found in the dessert valleys of Arizona. Of leaf-bearing trees which might constitute a protection against the powerful rays of the noonday sun there is an entire absence. A few isolated palms are found near some of the springs. Varieties of mesquite and yucca are common along the bottoms of the larger valleys. The most imposing plants are the giant cactus (supposed to be the *Cereus pringlei*), which sends its branching shafts at times to a height of 30 feet. The endless procession of these in some long valleys resembles at a distance the relics of a burned forest. Among the infinite variety of smaller cactus plants, the most vivid impression is retained of the one known to the Mexicans as the "choya," which at the slightest touch leaves a ball of spines sharper than a number 10 needle deeply buried in the flesh. Agaves are most abundant next to the cactus, the dried stems of the dead *Agave shawi* being often thick enough to resemble a nursery of young saplings. The most singular forms are what are locally known as "sirios" (*Fouquieria splendens* and *F. columnaris*), which often send their bare branchless stems 30 to 40 feet into the air. More like a tree is the low branching elephant tree (*Veatchi cedrocensis*), seldom more than 10 feet high, whose bark is said to be used by the Mexicans for tanning.

This whole region may be in one sense considered to be a mesa region, since at one time the present mesa formation extended from coast to coast, but at the present day the mesas are no longer continuous, and erosion has disclosed an underlying or buried topography whose general

features show considerable analogy with the more northern region described by Lindgren. The mesa belt proper adjoining the western coast is represented by a series of plateaus from 900 to 2,000 feet in elevation, separated by the deep canyon-like valleys of streams that drain the interior. Owing to the soft, crumbling nature of the beds, the escarpments are very abrupt and the topography has something of the character of the Bad Lands of the Great Plains.

The Coast or Western range is represented by a series of isolated peaks or ridges rising one or two thousand feet above the general mesa level, which are partly connected together by flat-topped ridges baseleveled down to the average elevation of the highest portion of the mesa region, but which in geological structure and composition belong to the same system of uplift as the higher peaks.

East of this range lie the interior valleys, broad, level or gently sloping plains 10 to 15 miles in width and with an elevation above sealevel of 1,800 to 2,200 feet, bounded and traversed by mesa-topped ridges and with occasional sharp peaks rising out of them. These interior valleys all drain to the Pacific through gaps in the Western range and rise gently to the eastward, the same gentle westward slope being noticeable in the mesa-topped ridges.

On the eastern edge of these valleys, at a distance of about 10 to 15 miles from the Gulf coast, a most sudden change in topographical structure takes place. The broad, level plains, in which the drainage courses are so shallow that their direction of drainage is with difficulty recognizable, give place to deep, narrow, tortuous ravines, descending a thousand or more feet within a few miles of the mesa-topped divide. These ravines wind among a series of sharp, jagged peaks, which evidently are the projecting summits of an older and partially buried mountain chain. The eastern range is represented in part by the summits of this buried range, in part by a series of isolated table-topped mountains rising to an elevation of 3,500 feet, which brings them above the summits of most of the sharper peaks to the eastward. On the immediate Gulf coast is a gently sloping mesa, of varying width, at the base of the eastern range. To the south of the region visited the buried mountains rise still higher than these table-topped mountains and send out spurs to the westward, which apparently cut off the interior valley in that direction. To the north, on the other hand, about 10 miles from the onyx quarries, they do not rise above the level of the interior valley, and the mesa-topped ridges sweep over them, descending in a series of terraces or steps to the Gulf coast.

The rocks of which this eastern buried range is composed outcrop so frequently in the bottom of the interior valley that it is probable that

this valley rests in part upon a plateau-like shoulder of the buried range, and that its form was not unlike that of the granite plateau described by Lindgren in the latitude of Ensenada.

From Gabb's descriptions it would appear that a similar topographical structure obtains for the part of the peninsula stretching south from latitude 29° to La Paz. The eastern range has for the most part a mesa-topped crest, broken here and there by projecting ridges which stretch in part across the peninsula and separate the interior valleys. The interior valleys, set off successively a little more to the southward and westward, become more extensive southward, one being described as stretching from La Purissima to Todos Santos (of the south), a distance of 150 to 200 miles, with an average width of 10 miles. The western range is apparently still more indistinct as a topographical feature and is not recognized by him, but the western mesa region is spoken of as stretching in varying width from Magdalena bay, in latitude 24° 30′, to cape Colnett, in latitude 31°.

## Geological Structure.

### *OBSERVATIONS BY PREVIOUS INVESTIGATORS.*

Before giving the facts observed in regard to the geological structure of the region examined by the writers, it may be well to give a brief résumé of those ascertained further north and south by the observers already mentioned.

Both Fairbanks and Lawson devote their attention mainly to the later formations composing the coast mesa of southern California, and of the interior Sierra it is only stated that it consists largely of granite, with some small areas of metamorphic slates. The mesa region, according to them, consists at different points of beds of the Chico-Cretaceous, Téjon-Eocene, Miocene, Pliocene and post-Pliocene formations. The Chico and Téjon beds are found in the high peninsula known as Point Loma and at La Jolla, on the coast immediately north of San Diego, between which they are folded into a shallow synclinal and are overlaid unconformably by a late Tertiary conglomerate 300 feet thick. Characteristic Chico forms, notably *Coralliochama orcutti*, occur in the lowest sandstone at the foot of the cliff of Point Loma, and typical Téjon forms are found at a horizon estimated at 1,200 feet higher and apparently comformable, though there is no direct superposition. At the highest point of the anticline at La Jolla Cretaceous beds are again exposed with characteristic forms, including *Baculites chicoensis.* The coast northward from La Jolla shows 400-foot cliffs of the Téjon beds, with characteristic Eocene fossils at the base, gradually sinking to the northward.

The mesa east of San Diego bay is formed of strata carrying Pliocene fossils, of which 69 species have been determined by Dall. Miocene strata have not been positively recognized here, but they are distinctly developed around the Santa Aña mountains, 100 miles to the north, and from there extend westward to San Pedro hill, on the coast south of Los Angeles, where they are partly covered by Pliocene and later beds which surround the base of the hill. They are doubtfully recognized in San Clemente, the southernmost of the Channel islands, and along the coast southward from San Pedro are gradually replaced by the Eocene (Téjon) beds, the relations between the two series not having been determined. Miocene strata are also reported from the western border of the Colorado desert, 70 miles east of San Diego, resting unconformably on supposed lower Cretaceous strata.

The upper portion of the "Mesa" is covered, according to Lawson, by Pleistocene sands and gravels both of marine and of stream origin, which extend to an average elevation of 800 feet above sealevel, marine post-Pliocene fossils having been identified 12 miles from the coast. From observations on the numerous terraces observed here and at other points further north, both on the coast and in interior valleys, he deduces a general depression of the region during Pliocene times and a post-Pliocene and probably recent elevation of the continental margin from San Diego to San Francisco of from 800 to 1,500 feet.

At Ensenada, some 60 miles south of San Diego, Lindgren reports a patch of coarse yellow sandstones and conglomerates in a protected angle on the south side of Todos Santos bay, which have hitherto constituted the southernmost known locality of the Chico-Cretaceous beds and which carry fossils of the new genus *Coralliochama* considered characteristic of the lower or Wallala division of this group. The beds dip 10° to 20° to the northward, and are partially covered by post-Pliocene sands and clays containing recent shells, which are also found at Sausal, on the north side of the bay. He also recognizes several terraces and indistinct remains of beaches reaching a maximum elevation of 500 feet above sealevel, indicating a recent elevation of the coast-line.

Lindgren surmises, from the existence of sandstone cliffs at cape Colnett, 70 miles south of Todos Santos bay, and from the resemblance of the mesa sandstones still further south, as described by Gabb, with the Todos Santos occurrence, that the former will be found to be of Cretaceous rather than of Miocene age, as Gabb somewhat doubtfully assumes.

The section of the mountain region from Todos Santos eastward as given by Lindgren is briefly as follows: The higher hills forming the coast range to the north and south of Todos Santos bay are largely composed of quartz-porphyrites and quartz-hornblende-porphyrites resting

on granite, which forms the floor of the depression in which the town of Ensenada is situated. These are consequently younger than the granite, and their rolled fragments contained in the Cretaceous beds prove them to be of pre-Cretaceous age.

On the immediate coast north of Sausal are recent eruptions of basalt of a somewhat unusual type which carries hypersthene and no olivine. These recent flows extend about 20 miles northward along the coast. The granite rocks forming the floor of the Ensenada basin are shown by microscopic examination to be more properly quartz-mica-diorites. About twelve miles east of Ensenada they are succeeded by a belt of metamorphic slates, both chloritic and micaceous, standing nearly vertical or with a steep dip to the east and associated with diabases. It is these rocks that carry the gold quartz veins, which are seldom, if ever, found in the granites that surround and are in part covered by them. They strike north-northeast and south-southeast.

The bottom of the interior valley of San Rafael, fifteen miles long and about ten miles wide, is 600 to 800 feet below the general level, a sunken area between two north and south faults, as he assumes, with knolls of slates and granite projecting through it. A short distance east of this valley the granite hills merge into a gently sloping granite plateau, which rises to an elevation of 5,000 feet and at one point is capped by an isolated patch of auriferous gravels, compared by Lindgren to the auriferous gravels of the Sierra Nevada. It then descends abruptly in a distance of five miles to the level of the Colorado desert, no metamorphic rocks being visible on the eastern escarpment at the point examined, but flat-topped mesas of volcanic rocks being discernible at its base further south.

The granite of the plateau, according to Lindgren, is a white coarse-grained hornblende granitite, or granite rich in plagioclase, with a somewhat dioritic facies, as is the granite in the latitude of San Diego, and resembles that of the Sierra Nevada.

He considers that the present metamorphic areas are small remnants of those that once covered the granite; that the great eastern escarpment is formed by an enormous fault of comparatively recent date, and that the auriferous gravel near the summit of the plateau is part of an old river channel that has been cut off by the fault. All these facts, together with the long western slope of the range and the recent volcanic outbursts at the eastern foot, constitute a close parallelism in geological structure between the peninsular Sierra and the Sierra Nevada.

From Professor Gabb's description of the desert region between La Paz and Santa Gertrudis (latitude 28° 30′), with regard to which his notes are more complete than on the region further north, which he apparently

passed over more hurriedly, the following brief outlines of the geological structure have been gleaned.

The most prominent geological feature is formed by what he calls the mesa sandstones, which lie for the most part in a comparatively undisturbed position and rise gently eastward toward the summit of a mesa-topped range running parallel with the Gulf shore, then descending in an abrupt deeply eroded escarpment for 10 or 15 miles to the coast. The long interior valleys, the most southern of which he describes as extending from La Purissima to Todos Santos, a length of 150 to 200 miles, with an average width of 10 miles, are apparently eroded out of the mesa sandstones. These sandstones are coarse grained and highly metamorphosed along their eastern edge when traversed by eruptive rocks. They also frequently contain eruptive material, pebbles and bowlders of eruptive rock sometimes forming the bulk of their material. Over these, sometimes showing direct unconformability, lie fine-grained argillaceous sandstones and shales, with a calcareous and highly fossiliferous stratum near the top containing casts of living species of shells which he considers of post-Pliocene age. In the mesa sandstones no fossils were found by him, but from a few fossil oysters sent in from cape Saint Lucas he assumes a probable Miocene age. The post-Pliocene sandstones usually lie on the lower margins of the mesa on either coast, covering the eroded mesa sandstone to an elevation of several hundred feet above the sea-level, and are more continuous on the west than on the east coast, extending, according to him, with few interruptions, the entire length of the coast from Magdalena bay to cape Colnett. The mesa structure is interrupted at various points by cross-ranges, of which the most notable is the recent volcanic belt extending westward from Los Tres Virgines in latitude 27° 30′, and a mass of older granite mountains near the east coast which in places project above them about the latitude of 28° and apparently extend up to the southern border of the region examined by the writers.

Gabb also mentions recent gravel formations filling the lower valleys, which are perhaps more recent than the post-Pliocene beds and which also form well defined terraces northward from Todos Santos (of the south) 60 feet high.

Of the southern point of the peninsula he says:

"All the higher ridges are made up of granites and syenites, and formed, during the deposition of the heavy bedded mesa sandstones, an island of considerable height and very irregular outline."

Associated with the granites are mica slates which apparently form the country rock of the metalliferous veins of this part of the peninsula.

The French engineer and geologist Ed. Fuchs,* in reporting on the copper deposits of Boleo, on the east coast, in the vicinity of Los Tres Virgines, described a gently sloping plateau made up of tuffs and conglomerates, the latter with calcareous cement and fossiliferous. The fossils are *Cardium*, *Pecten* and other bivalves probably of late Miocene or early Pliocene age. The deposition of these beds was preceded by trachytic eruptions across the peninsula, and followed, since the elevation of the Boleo plateau, by the basaltic eruption which formed the neighboring volcanic peaks of Los Tres Virgines. The final phases in the geological history have been, according to him, the diluvial denudation and the carving of the modern valleys.

### *THE REGION UNDER CONSIDERATION.*

*General Remarks on its geological Structure.*—In the region examined by the present writers the feature that first strikes the observer is the proportionately great influence that the great diurnal changes of temperature have had in the disintegration and abrasion of the rocks as contrasted with the action of water which plays so important a part in other regions. The gravels resulting from the disintegration of eruptive rocks consist mainly of angular fragments, and each fragment is found to consist of an aggregate of minerals scarcely at all discolored by oxidation and differing from the parent rock mainly in their loosely coherent condition. The steeply upturned and highly metamorphosed beds of the older sedimentary rocks weather into splintery forms and thin fragments of arrowhead shape, whose corners, even in the stream bottoms, are but slightly worn. On the other hand, the rounding of the massive rocks, such as the coarsely crystalline diorites and granites, by atmospheric action is even more marked than in moister regions; so that low ridges just projecting above the valley level often consist of bowlder-like blocks resembling a train of erratics or parts of an old moraine. The manner of distribution of the great accumulations of sand and gravel in the broad arroyos and larger valleys of the interior show that they have been subjected to no continuous action of running water, but only to occasional freshets resulting from infrequent and local rain-storms. Except on the present beaches, where they have been exposed to wave action of the present ocean, rounding of the water-worn pebbles and bowlders now found, which are almost exclusively of massive rocks, must evidently be assigned to some earlier geological period, modern waters having only had the effect of slightly concentrating material derived from the disintegration of the older beds.

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*Bull. Soc. Geol. de France, 3me xiv, 1886, p. 79.

It is only within comparatively short distances of the present coast-line that narrow and deep canyon-like ravines are found, the interior valleys being generally broad and shallow, with very indistinctly outlined stream beds.

For purposes of geological description the region examined may be divided into the coast or mesa belt, the western range, the interior valley, and the eastern range. The immediate Gulf coast was not visited.*

*Coast or Mesa Belt.*—This area has an average width of 10 to 15 miles, and in it, so far as observed, no older rocks occur than horizontally bedded, loosely aggregated clayey sands, sandstones and conglomerates of which the lowest horizons carry characteristic forms of the Chico-Cretaceous. In a higher horizon of this apparently conformable series a characteristic fauna of the Téjon-Eocene has been found, and in still higher beds a few forms of probable Miocene age were observed. None of these beds show evidence of any considerable disturbance, though in a few instances dips of 10° to 15° and slight displacements with a throw of only a few feet have been observed. They have, however, been extensively eroded, and later deposits of post-Pliocene and possibly also of Pliocene age have been deposited upon their eroded surface. Recent eruptive rocks, both acid and basic, have cut through them and in places have been important factors in shaping topographical forms by protecting the softer beds from erosion.

The best exposures of the lower beds were found between Canoas and Bluff points (see plate 19), where they present perpendicular bluffs, facing the sea, from a few hundred up to nearly a thousand feet in height. These are being rapidly undermined and eaten back by the action of the waves, so that between the two points the coast-line forms a bow-like reëntering curve, set back 3 to 5 miles from a line drawn between the points. From either point the land rises in a series of steps or broken terraces to an extensive plateau, cut on the sea faces by short, narrow, branching ravines and presenting in general continuous bluff faces inland.

Midway in the reëntering curve between Canoas and Bluff points is the Playa Santa Caterina, where is a gap a mile or two in width between the bluffs bordering the ocean, formed by a broad valley in which are two modern stream beds draining the interior region. They are divided at the shoreline by a flat-topped ridge of Chico beds, near the top of

* On plate 19 is given a generalized section across the peninsula on a line running approximately from Playa Santa Caterina through the onyx quarries. Topographical features at some distance from this line are brought in to illustrate the general structure. Though not drawn to scale, care has been taken to make the section as close an approximation to nature as the data would admit. Distances were estimated in travelling to and fro and checked by rough triangulations made with a prismatic compass. The vertical scale is intended to be about four times larger than the horizontal.

which is the remnant of an ancient stream bed whose bottom is now about 100 feet above tide-water, and which is filled by a conglomerate of large bowlders and water-worn pebbles of massive rocks. This conglomerate, which is cemented by lime and iron, is so much more resisting than the soft clays of the Chico formation that the huge bowlders that fall down as the cliff is undermined by wave action form a point projecting out several hundred feet beyond the average coastline. These conglomerates are probably of the same age as those which are found at various points in the canyons of the interior, and their formation evidently dates back to a time when, after the carving out of the general system of modern drainage, the waters of the ocean reached a higher level than the present and the old drainage channels were partially filled up to the then baselevel. Subsequent erosion, while cutting down to a somewhat lower level and following the same general lines, has often eaten more readily into the softer beds at the sides of these recent conglomerates and left patches of them still standing, which sometimes form one wall of the canyon a hundred or more feet above its present bottom.

The modern stream beds from Playa Santa Caterina are almost at baselevel for some ten miles inland, at about which distance eruptive rocks appear from under the Cretaceous and recent beds, and then rise rapidly, reaching an elevation of about 1,500 feet within I5 miles of the coast, on the partly buried slopes of the Coast range.

Both in the broad valley and on the mesa slopes are relics of terraces which evidence a successive rising of the land above the ocean.

The lower beds exposed in the bluffs along the coast have a gentle inclination northward and southward from Sandstone point, about three miles north of Playa Santa Caterina, where massive sandstones form a slightly projecting headland. In these sandstones carbonized plant remains, too indefinite for identification, were found, and in the cracks of the immediately overlying sandy clays were traces of petroleum. From these beds and from calcareous layers about 200 feet above were obtained the following forms as determined by Mr T. W. Stanton:

| | |
|---|---|
| *Arca breweriana*, Gabb. | *Inoceramus*, sp. undetermined. |
| *Baculites chicoensis*, Trask. | *Ammonites*, sp. undetermined. |
| *Tessarolax distorta*, Gabb. | *Ostrea*, sp. undetermined. |

They correspond with forms found in the Chico beds of California and Oregon.

From rolled pebbles of impure limestone obtained along the beach to the south of the Playa, which had evidently fallen from the cliffs above, and from a bed of similar composition in place at what was assumed to be about 1,200 feet higher in horizon, at San Carlos anchorage (collected

by Mr A. D. Foote), eight miles north of Bluff point, the following forms were identified by Mr T. W. Stanton:

*Cardita planicostata*, Lam.
*Leda gabbi*, Conrad.
*Urosyca caudata*, Gabb.
*Nucula*, sp. undetermined.
*Pectunculus*, sp. undetermined.
*Tellina*, sp. undetermined.
*Turritella*, sp. undetermined.
*Dentalium*, sp. undetermined.
*Crassatella*, sp. undetermined.

and are considered by him to belong undoubtedly to the Téjon-Eocene.

The beds carrying Chico and Téjon fossils were not observed in direct superposition, but from the negative evidence that no decided unconformities were detected at any of the points examined, it is assumed that the two series are conformable, or that in any case no considerable disturbance of the strata took place between the times of their respective depositions.

The great mesa or plateau, 15 miles long and 6 to 8 miles in width, which extends from the valley of Santa Caterina northward beyond San Carlos, has an elevation of from 1,800 to 2,000 feet, being somewhat higher at the northern end. The greater part of its surface is apparently capped by basalt flows, which have protected it from erosion. From a distance can be distinguished conical points rising above the level of the mesa, known as the "Sombrero," the "Hat," etcetera, which resemble recent craters in general form. At one point on the coast fragments of the basalt, cemented together by crystalline calcite, have fallen to the foot of the bluff in huge masses and form a projecting point on the coast-line.

For about a mile beyond Sandstone point the beach is covered with beautifully rounded pebbles of porphyries and a great variety of hard rocks, mostly older eruptives, whose material must have come down a ravine which drains the western face of the plateau and descends very rapidly from its summit. As no such pebbles were observed in the Chico or Téjon series, nor on the beaches to the south where no upper beds remain, it is thought probable that the mesa sandstones, which are characterized by an abundance of eruptive material, may form the upper portion of this plateau.

Northward from San Carlos, as seen from the ocean or from commanding points of view in the interior, the same character of beds, with their characteristic bad-land topography, extend northward to the Rosario ravine.

The hamlet of Rosario is situated a few miles from the sea, in this ravine or canyon, which extends inland for some 10 or 15 miles with very gradual rise of its beds, and carries a small stream of running water that in dry seasons sinks below the surface sands. The cliffs of the

canyon walls are eroded into castellated forms that recall the buttes at Green river, Wyoming, familiar to travellers on the Union Pacific railroad. Opposite Rosario the bedding planes have a dip of 15 degrees to the northeastward, while the surface of the mesa is quite horizontal, and from the pebbles and recent shells on its surface evidently represents a higher level of the ocean waters, which have baselevelled it at about 1,000 feet above present sealevel. For a few miles north of the mouth of the Rosario canyon the bluffs come close to the present coastline and then gradually retreat, until opposite San Quentin they are about eight miles inland. The immediate shore is first a terrace about 200 feet above sealevel, then at the mouth of the Sorrocco valley a triangular shaped Quaternary delta hardly 50 feet above sealevel, covered with rolled pebbles and recent marine shells. The older beds forming the mesa region in this latitude, though not markedly different from those between Bluff and Canoas points, contain a larger proportion of conglomerate material and several fossiliferous beds of recent looking shells, among which were recognized *Mytilus californianus* and a fragment of a *Pecten*, like *P. cerrosensis*, which Dr Dall regards as indicating a probable Miocene age. These are the beds seen by Gabb on his trip and called by him "mesa sandstones." No evidence of unconformity between these and the Téjon beds was observed, and it seems probable that they may constitute the highest part of the mesa at Bluff point, but this was not determined by fossil evidence.

Northward from Sorrocco river the bluffs of the mesa formation retreat gradually from the ocean, and at San Quentin are separated from it by the sandy plains of Santa Maria, about 8 miles wide and but a few feet above sealevel, which are the northern continuation of the depression of the bay of San Quentin. The immediate coastline at San Quentin is formed by a group of six conical hills of basalt, from 400 to 800 feet high, which, judging from the uneroded character of the lava flows which have issued from their flanks, must be of very recent eruption. One of these flows extending southward about seven miles forms the low, narrow tongue of land known as cape San Quentin. It is evidently the superior resistance of these hard lavas that has thus far protected the plains of Santa Maria from the encroachments of the sea.

*Western Range.*—In the present topography the western range is very ill defined, and consists of a number of irregular ridges and isolated mountain masses 15 to 20 miles from the coast, the highest summits of which are probably less than 4,000 feet above sealevel. Between the peaks are broad transverse valleys and flat topped ridges whose higher summits have the same general level with those of the higher plateaus of the mesa region, that is, about 2,000 feet. Rounded pebbles and an

occasional fragment of recent shells were found on these summits, which strengthen the opinion that this was a peneplain of recent times, probably formed at the time of the greatest submergence since the deposition of the mesa sandstones.

The range was traversed on two lines, that of the arroyo of Santa Caterina, shown in the section (plate 19), and that of the Rosario arroyo. The river bed or arroyo of San Fernando crosses it about midway between these two. Near the mission of San Fernando is a considerable development of sedimentary beds, one of which is a much altered bluish limestone containing unrecognizable fossils, which is probably either of early Mesozoic or Paleozoic age. The beds have a steep dip to the eastward, at one point are overturned against a considerable body of acid eruptives and diorite. On the line of the Rosario arroyo it consists mainly of diabase, with acid eruptives and diorites on their eastern flank; the latter cut the diabases, and are succeeded on the east by an extensive flow of rhyolite capping the mesa ridges which extend out into the interior valley. A little further south diorites seem to form the main mass of the flat topped ridges which here represent the range, and which are flanked on the east, at the border of the mesa region, by recent tuffaceous rocks in which is found one of the few springs of the region. Along the line of the section south of San Fernando diorites again predominate, and in these occur deposits of copper sulphides, one of which has been quite extensively mined.

It was not possible to determine the relative age of all the varieties of eruptive rock observed, but the older eruptives are evidently pre-Chico, while some of the recent eruptives are certainly more recent than the mesa sandstones.

The rocks described above as acid eruptives are compact and sometimes brecciated quartz-porphyries of greenish and brownish colors, at times quite aphanitic and again showing small phenocrysts of feldspar and more rarely quartz, sufficiently developed to be recognizable by the naked eye. Chemical tests in the more aphanitic varieties yield 70 to 75 per cent silica.

The most common form of the diorite is a pinkish gray finely granular rock which in thin section shows a hypidiomorphic granular aggregate of quartz and triclinic feldspar with pale green hornblendes in part or wholly altered to epidote. There are also a few sphenes and the usual iron ores.

In the upper Santa Caterina valley, which crosses the range diagonally in a nearly north-and-south direction, a very considerable mass of underlying granitic rock is exposed over an extent of about 10 miles along the bottom of the valley, which apparently grades into the finer-grained

diorites surrounding it. Along the center of the valley a low ridge of rounded blocks of this very massive rock has the appearance at first glance of a morainal ridge with huge erratics, but examination shows that the rounded forms are merely the result of weathering under the peculiar climatic conditions of the region. The granite is an even grained, granular rock, thickly studded with small black scales of mica and small hornblendes. In thin section it shows a hypidiomorphic granular aggregation of quartz, feldspars, black mica and deep green hornblende, with a sprinkling of iron ores, apatite and rarely zircons. It resembles the granites of the Sierra Nevada.

Westward along the line of the section this granite is succeeded by the finer-grained quartz-mica-diorite described above, and then by a belt several miles in width of recent eruptives, which form low, rounded hills adjoining the mesa region. These appeared to be mostly rhyolites, and to have cut through the sedimentaries of the mesa region, though it was not possible to obtain unquestionable evidence of the latter fact.

On the east, or at the head of the Santa Caterina valley, capping the flat ridges which form the western divide of the interior valleys, was found a rather remarkable rock of the hypersthene-andesite type, showing microscopically small olivines and white feldspars, with occasional black hornblendes in a dark gray matrix. In thin section it shows a decided andesitic groundmass of augite and plagioclase microlites, with the usual iron ores and abundant colorless olivines, pale hypersthenes, small pale green augites and an occasional dark basaltic hornblende with black border.

Abundant chalcedony and flint concretions with dendritic markings, constituting the popularly known moss-agates, are found on the eastern slopes of these ridges.

*Interior Valley.*—The interior valley which was visited by the writers is probably that designated by Gabb as the plain of Buena Vista. In about latitude 30°, or a little north of the line of the section, its width on a northeast-southwest line, or at right angles to the trend of the peninsula, is over fifteen miles, an almost level plain with a slight rise toward its eastern rim, which rests on the submerged flanks and crests of the eastern range. Its elevation varies from about 2,000 feet on the western to 2,300 feet on the eastern edge. To the southward its width is contracted by the encroachments of the bounding ranges which send out spurs or ridges into it, and in the far distance appear to merge together. The spurs from the eastern range are flat topped in great part and composed of horizontally bedded material, which, where examined, consisted largely of volcanic ash carrying abundant fragments of basic eruptives. These are evidently the mesa sandstones of Gabb. Those from the western

range, on the other hand, are composed largely of eruptive rocks and appear to be projecting portions of the older mountains laid bare by erosion, but in a few cases are mesa-topped ridges capped by horizontal lava flows of later age than the mesa sandstones.

To the north the valley appears to grow wider, and out of its midst rise a few conical peaks, the most prominent of which, known as San Juan de Dios, about 20 miles north of the line of the section has a remarkably graceful outline and a probable elevation of over 4,000 feet. It is composed in great measure of eruptive rocks, among which felsite, diabase, liparite and basalt were recognized, while erosion had disclosed on one side an underlying coarse quartzite. At its base is one of the rare springs of the region. Similar peaks are seen to rise out of the plain far to the northward at probable distances of 10 to 15 miles apart.

The slope of the broad stream beds in the lower part of the valley is so imperceptible that the direction of its drainage is difficult to determine, but aneroid observations indicate that the portion examined is drained through the gap in the western range at the ruined mission of San Fernando (elevation about 1,800 feet), and thence probably by the San Fernando river bed to the Pacific ocean. Limited portions of the eastern edge to the north of the line of section are drained by deep and narrow arroyos of more recent formation into the gulf of California. The present bottoms of the valley are occupied by recent deposits of porous limestone or travertine and coarse conglomerate with calcareous cement containing rounded fragments of both eruptive and sedimentary rocks in great variety and of varying size up to several feet in diameter. The evidence of wells which get water in the lower parts of the valley at 40 to 60 feet below the surface, and of adjoining mesas in the valley which afford partial sections show a present thickness of little over 100 feet of these beds, but their elevation in shallow ravines, notably the one on the southeastern edge of the Buena Vista plain, in which are the New Pedrara onyx deposits, and remnants of calcareous conglomerates remaining on the flanks of the bounding ridges at other points indicate that the original thickness of these deposits may have been several hundred feet, and that the greater part has already been removed by erosion. No fossil evidence was obtained as to their absolute geological age, but the character and position of the deposits indicate that they were laid down in an enclosed body of water, probably an interior lake, of comparatively recent date. What remains of these beds barely serves to smooth over the inequalities of the underlying mountains whose component rock masses often outcrop across the stream beds, especially along the eastern portion of the valley. Even where there is no actual outcrop the appearance of frequent fragments of granite or sedimentary rocks, as

the case may be, indicate that these rocks are to be found in place near by and not far from the surface. In some cases the ground is whitened over considerable areas by the abundant small fragments of vein quartz resulting from the disintegration of the underlying slates.

The relative age of the interior lake beds may be assumed to bear some relation to that of the calcareous conglomerates already mentioned which partially filled the earlier canyons of the Pacific slope. After the deposition and subsequent elevation of the mesa sandstones, which are assumed to be of late Tertiary age, there must have been a long period of erosion, during which the interior valley was carved out and drained through the deeper canyons running to the Pacific ocean. This was apparently followed by an extensive submergence of 2,000 feet or more, since which time the whole peninsula has been gradually rising by periodic movements, with considerable baseleveling in the intervals.[a]

The present elevation of the mesa-topped ridges of the western range indicates a baseleveling of the region at an elevation of about 2,000 feet above present sealevel. This might have filled up all the outlets of the interior region across the western range and admitted of the enclosure of a body of water up to that level, but to account for the present position of the deposits on the eastern side of the valley it is necessary to assume a subsequent differential movement by which that side has been raised a few hundred feet more than the eastern side.

*Eastern Range.*—The older or buried eastern range is made up of granite and gneiss, with highly altered sedimentary strata flanking it on the northeast which stand either vertical or with a steep dip to the eastward and strike about northwest, or somewhat more to the west of north than the general trend of the peninsula. The present divide, on the other hand, follows the general trend of the coastline at a distance of 10 to 15 miles from it, and is marked in general by abrupt escarpments along the eastern edge of the desert plain.

To the north of the limits of the field of observation, beyond the thirtieth parallel, the summits of the older range have been planed off and their depressions so evenly filled up by the more recent deposits that they play no part in the present topography of the country. To the south, however, where east of the present divide they have been denuded of the more recent deposits, or still further south, where they were never completely covered by these deposits, they form conspicuous and striking topographical features, in marked contrast with the prevailing horizontal lines and broad, shallow valleys of the western portion of the peninsula.

In the northern region the desert plains and flat topped ridges of mesa sandstones rise very gently from the west to the divide line, which al-

most invariably presents an abrupt escarpment to the east, overlooking a region deeply scored by narrow gorges several hundred feet in depth, with almost vertical walls. Here the divide line is marked by occasional isolated table-topped buttes, capped by rhyolite, which rise 500 to 1,000 feet above the desert level and serve to mark the original level of the mesa sandstones, which have been protected from erosion by the cap of more enduring rock. These rhyolites are generally of earlier date than the lake beds. The top of the mesa sandstones as thus determined is about 3,000 feet above present sealevel, and their maximum observed thickness 800 feet. Augite-andesite flows, apparently of more recent date, are found capping intermediate portions of the divide. The contrast in topographical structure between the regions east and west of the divide is here less marked than in the region to the south, as on both sides approximately horizontal lines prevail. The surface of the mesa-topped ridges slopes upward toward it from either direction, but the slope is much greater on the eastern side, and the ridges descend toward the Gulf in a series of step-like terraces, while the whole eastern region is deeply scored by narrow steep sided ravines from a few hundred to a thousand feet in depth. The upturned beds of the metamorphic series are well exposed along the walls of these ravines, often reaching the surface of the intervening mesas. They are also seen in the shallow stream beds of the desert plains on the west, and, as already remarked, often outcrop through the thin covering of the lake beds for a considerable distance out on to the desert.

South of the thirtieth parallel the summits of the buried range rise gradually, and east of the divide are completely denuded of any covering of recent beds that they may have had. They also spread out to the eastward, approaching more and more closely to the Gulf coast, and south of the limits of the field of observation, or 20 miles south of the thirtieth parallel, they constitute a high granite range extending 10 or 15 miles westward into the interior valley and effectually cutting off any view of the country beyond.

The region in the vicinity of the New Pedrara onyx deposits, a few miles south of the thirtieth parallel, shows well the general structure of the eastern range as presented in generalized form in the section on plate 19 and will hence be described in some detail.

The principal onyx deposits are situated in a shallow ravine or eastern arm of the interior valley, between two ridges of mesa sandstone, at an elevation of about 2,300 feet. Since the denudation of the granite bed of this ravine of its former covering of mesa sandstone it has been filled to a depth of about a hundred feet by alternate beds of travertine and calcareous conglomerate, which were probably contemporaneous and at one time continuous with the lake beds of the interior valley.

The winding bed of the modern stream cuts into the travertine deposit, exposing at one place a cliff of over 20 feet in height, showing three distinct layers of Mexican onyx, one of which is over three feet thick, interstratified with the travertine, while for a distance of nearly a mile down the ravine sheets of the more resisting onyx cap the little travertine mesas on either side. The occurrence of the onyx, which is a thermal spring and surface deposit, in successive layers, separated by travertine and resting on conglomerate, indicates a probable successive rise and fall of the waters of the lake where the travertine was deposited, which would have admitted of some slight erosion of the deposit in the periods when the lake waters had temporarily retreated, a hypothesis that was confirmed by the finding of some fragments of onyx in the upper travertine beds.

At the head of the ravine the travertine beds end abruptly in an escarpment, beyond which one descends rapidly 500 feet through winding ravines, between sharp, jagged ridges of a metamorphic rock, to the bed of the Tule arroyo, a winding, V-shaped gorge, which runs northward about ten miles, then northeastward to the gulf of California, draining the whole region east of the divide. At one point this gorge widens out into quite a valley, in which are travertine deposits about 50 feet in thickness, with layers of onyx in the upper part. Relics of the thermal action are found at the present day in a little effervescent spring, known as the Volcan, which issues from the top of a dome-shaped mound of calcareous tufa in the narrow bottom of the ravine before it opens out into the valley containing the travertine deposits.

These travertine deposits are entirely isolated and have no present connection with those of the interior valley to the east of the divide, their level being about 400 feet lower than the divide where the nearest lake-bed deposits end. The similarity of their composition, their relations to the underlying rocks, to the onyx formation, and to modern erosion all suggest, however, a common origin with the lake beds, and, if once connected with them, there must have been a differential movement since their deposition which produced the present difference of level.

Beyond the Tule arroyo to the eastward arise a series of sharp, jagged peaks, which attain a maximum elevation of about 3,000 feet, deeply scored by a most intricate system of deep, winding ravines, quite impassable except to foot travellers, and which are in most striking topographical contrast to the level valleys and plains of the region west of the divide. Within these hills at various points are placers from which the Mexicans obtain considerable coarse gold by dry washing during the months immediately following the spring rains. At other seasons there

is not enough water to support life. They are composed of distinctly stratified sedimentary beds standing on edge and striking northwest and southeast, but which are so highly metamorphosed and so blackened and splintered by the weathering of this arid region that their original character can no longer be determined. They are mostly dark silicious slates and fine-grained mica-schists. Some beds have all the external appearance of limestones in their granular structure and thin white veins, but their present composition shows no trace of lime and is almost entirely silicious. They are traversed by well defined dikes which are also intensely altered. A specimen from one dike was examined microscopically and found to be a metamorphosed clastic, composed of irregularly notched quartz granules with sporadic patches of pale green hornblende and considerable infiltrated calcite.

Among the more striking rocks in this metamorphic series, at the northern limits of the area observed, was a fine grained hornblende rock which microscopic examination shows to be probably an altered diorite. The groundmass consists of an aggregate of plagioclase feldspar, apparently anorthite, with fibrous hornblende containing inclusions suggestive of interpolations of hypersthene and diallage. Associated with this was a grayish massive rock thickly studded with short stout crystals of black hornblende 2 to 5 millimeters in diameter and 5 to 8 millimeters in length. Microscopical examination shows the groundmass to be a granular aggregate of almost colorless augites with a few plagioclase feldspars, and the rock apparently belongs to the group of hornblende-pyroxenites of Williams. When collected these rocks were supposed to be interstratified with the metamorphic series, as their outcrops had the same general strike; the result of microscopical examination indicates that they are probably altered intrusive sheets.

The flat-topped ridge of mesa sandstones south of the ravine in which the principal New Pedrara onyx deposits occur is thickly strewn with subangular blocks of augite-andesite, which have apparently weathered out as the soft ash of which the beds are composed has worn away. At the eastern extremity of this ridge, on the very crest of the divide, is a high basalt-capped mesa, nearly a mile in diameter, called by us Bluff point. It has an elevation of about 3,500 feet, and overtops all the highest summits within a radius of 15 to 20 miles, thus offering an admirable point of view from which to study the physical structure of the region. The basalt cap has an aggregate thickness of 500 feet, and consists of an upper layer of dark vesicular olivine-bearing rock 350 feet in thickness resting on 150 feet of gray, fine-grained rock containing abundant large crystals of olivine. The upper layer has a dark smoky glass base with the usual microlites of feldspar and augite and small pheno-

crysts of augite, olivine and feldspar. Between these flows a zone of decomposition several feet in thickness, colored brilliant red by peroxidation of the iron, makes a prominent line, visible from a great distance, on the bluff faces which almost completely surround the mesa.

The surface of the mesa has a gentle slope westward and ends to the eastward in an almost perpendicular escarpment overlooking the Tule arroyo 1,500 feet below, which has here widened out into a considerable valley that drains the northern slopes of the White range far to the south. Beyond this valley, partly cutting off the view of the gulf of California, lies the group of dark rugged peaks of metamorphic slates, called the Volcan Peak group, which the Tule arroyo almost completely encircles in its circuitous course to the sea. Through the gaps in this range can be distinguished the pale blue waters of the gulf of California, and occasionally portions of the coast-line, as well as several of the group of small islands which lie a few miles off the shore in this latitude and whose abrupt outlines show them to be probably projecting points of the buried metamorphic ranges.

The arms of the interior valley which lie to the south and west of the Bluff Point mesa have a floor of granite which is entirely denuded of the mesa sandstone covering and of the lake beds, if the latter ever covered it. The granite is a light gray rock of normal type, consisting of two feldspars, quartz and both white and brown mica. Hornblende was not observed. From general appearance and association it would appear to be a distinct and older rock than that found in the western range. To the south of these valleys the White range, composed of the same granite, stretches some 10 or 15 miles east and west across the peninsula and apparently cuts off in great measure the interior valley in this direction. As no contacts were found it was impossible to determine the relative age of the granite and the metamorphic series.

Circumstances rendered it impossible to visit the Gulf coast, in spite of its being probably less than fifteen miles distant in a direct line, but the different distinct views obtained of it showed that a strip of mesa land most everywhere separates the foothills of the buried ranges from it, which would seem to be parts of the same series of deposits that have been designated the mesa sandstones.

No direct evidence was obtained either for or against the hypothesis that the Chico and Téjon beds once stretched entirely across the peninsula. Nothing that could be lithologically identified with them was detected in the region examined, and no organic remains whatever were observed in what were called the mesa sandstones; still, the negative evidence, combined with the impression derived from the general structure of the region, has given to the writer a strong feeling that these earlier beds were confined to the western coast belt.

## General Conclusions.

In comparing the thirtieth parallel section of the Lower California peninsula, as indicated by the above noted observations, with that described by Lindgren near the thirty-second parallel, the most striking fact is the parallelism in structure of the older pre-Cretaceous mountain mass. In either case there is an eastern uplift of granite and metamorphic slates, and a western one composed largely of eruptives probably of more recent age than the granite. The sedimentary beds or metamorphics, with their associated intrusives, bear evidence of intense dynamic action and consequent alteration, and of long continued erosion and degradation. That they have been to a much greater extent removed in the higher northern region, and that the underlying granite consequently occupies a so much larger proportion of the exposed surfaces, is in so far an evidence that the relative difference of level of the two regions had existed prior to the Cretaceous transgression, which left the northern region exposed to continuous degradation, while it protected the southern region, so that its present conditions beneath the covering of more recent beds represent those which might have prevailed in the northern region before that time.

The petrographical parallelism between both sedimentary and eruptive rocks of the respective regions is also very close, except in the case of the granite of the western uplift, but the examination of the southern granite body was so superficial that one is hardly justified in considering this apparent difference as essential. The metamorphic slates in either region are, moreover, gold-bearing and the granite apparently not. The eastern escarpment in either case represents a probable line of displacement, but in the southern region it is less sharply defined and may have been distributed over several lines of faulting. The evidence is here rather opposed to Lindgren's assumption that the great movement is of very recent date, since the present position of the recent beds on either side of the divide indicates a relative change of level since their deposition that is to be measured by hundreds rather than thousands of feet.

On the other hand, the general deduction that the depressed area of the gulf of California and its continuation in the desert valleys to the north bears the same relation to the Peninsular Sierra that the Great basin does to the Sierra Nevada appears to be borne out by what is known of the general structure of the former; and if, like the Great basin, this at present depressed area was once relatively higher than that which now constitutes the mountain range, it would have formed a barrier in the ancient ocean which would account for the faunal differences which appear to prevail between the Cretaceous life as now known on the Pacific coast, and in Mexico and Texas.

The little that is known of the structure of the underlying or pre-Cretaceous mountain system of the peninsula seems to indicate that its larger general features have an *en echelon* character that is so common among the larger chains of the Cordilleran system of which the Colorado Front range of the Rocky mountains is a most striking example. In the present case the chain taken as a whole has a north-northwest trend, while its component mountain ridges have a trend of about northwest, with considerable depressions or bays opening out to the northwest between the overlapping ends of these ridges.

In the gradual submergence which followed the period of folding and erosion that culminated, according to the latest evidence, about the close of the Jurassic time, the first Cretaceous beds would have been deposited in the bottoms of these longitudinal depressions, and if they grew shallower or were closed to the southeast by the saddles between the echelon ridges along the main divide, the earlier beds would have been confined to the region west of the divide, even if the larger area to the east of the divide had already commenced to sink. If the continental submergence continued, as it evidently did in Lower California up to near the close of the Tertiary, the later deposits might have extended entirely across the peninsula without showing any evidence of discordance or want of continuity with the earlier beds.

An examination of the shore platform or limit of the 100 to 200 fathom curve around the coast of Lower California, which is generally regarded as the proper dividing line between the continental and oceanic areas, shows that the peninsula is a very narrow mountain mass, descending generally to the southward and probably dying out entirely in the Pacific ocean to the west of the coast of Mexico. On the east the gulf of California, north of the straits formed by the great islands of Tiburon and Angel de la Guardia, belongs to the shore platform or forms part of the valleys to the north, having no depths below 200 fathoms, while south of these straits its bottom drops rapidly to 5,000 feet. On the west coast the 100-fathom line follows a comparatively direct course from headland to headland, disregarding the great reëntering curves like Viscaino bay, while oceanic depths of 1,000 to 1,500 fathoms are found within 20 to 30 miles seaward from these headlands. Between the headlands the present coastline shows a tendency to form loops opening out to the northwest, which suggest the *en echelon* depressions in the pre-Cretaceous topography alluded to above, and which would bear a closer resemblance to their form had not recent eruptions of volcanic rocks interfered with the uniform degradation of the soft beds which were deposited in them.

The first depression south of the international boundary is the very small one at Todos Santos bay, in which but a small remnant of Chico beds remain. From there to cape Colnett the older rocks form the im-

mediate coast. From cape Colnett the flanks of the buried range appear to follow a due southeast course, leaving a gradually widening belt of Cretaceous beds between them and the coast, which has been protected from recent erosion by the lavas of San Quentin and similar phenomena. South of Canoas point, if the southeast direction were strictly followed, the flanks of the buried range would approach nearer to the present coast-line as Viscaino bay widens landward, and the shore topography given on the hydrographic charts would indicate that this is the case. The character of the southeastern shores of Viscaino bay indicate that the depression extends for a considerable, though unknown, distance in that direction. On the southwest of Viscaino bay is another uplift of older rocks, the projecting summits of a second buried ridge whose culminating points form Benito and Cerros islands and the coastline at point San Eugenio and for some distance southward.

In the next reëntering curve, around and beyond Ballenas bay, the coast is again a low mesa country, presumably of Cretaceous and more recent beds, which may be part of the Viscaino bay depression or an independent one set off a little to the southwestward. Gabb's descriptions indicate that the depression extends a long distance southeastward, and the map shows it to be on the line with the bay on the Gulf coast north of La Paz.

At cape San Lazaro and in the islands outside of Magdalena bay is a third projecting ridge of older rocks which may form part of the uplift at the extreme end of the peninsula south of La Paz.

Diller and Stanton * have shown that the Chico and Téjon formations, formerly considered conformable and part of a continuous series, are separated by a marked unconformity in northern California and Oregon.

Whether representatives of these lower formations exist in Lower California can only be determined by further exploration. The Todos Santos beds of the Chico would seem from their fauna to be of lower horizon than those between Bluff and Canoas points. On the other hand, probably several hundred feet of these beds are below sealevel at the latter locality and probably form the floor of Viscaino bay.

The fact that since Cretaceous times these formations seem not to have been flexed and altered, as they have been in the Coast range of California, but occur almost in the attitude of deposition, renders the peninsula a most favorable point for their study, except for its inaccessibility.

Since the great depression near the close of Tertiary times our observations go to show that the whole peninsula has taken part in the consecutive movements of elevation which have been outlined by Mr Lawson for southern California, though they were not sufficiently exact to determine an actual correspondence in the number or altitude of the different terraces formed during the progress of this elevation.

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*Bull. Geol Soc. of Am., vol v, p. 436.

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# EASTERN BOUNDARY OF THE CONNECTICUT TRIASSIC*

BY W. M. DAVIS AND L. S. GRISWOLD

(*Read before the Society December 28, 1893*)

CONTENTS



## Previous Studies.

The previous studies of the Triassic formation of Connecticut, carried on by the senior author of this paper, with the aid of several assistants during various summer vacations for the United States Geological Survey, as well as independently during successive sessions of the Harvard summer school of geology, have been reported upon at different times, as mentioned in a list of papers in a previous number of this Bulletin.† Since then a popular essay, "The Lost Volcanoes of Connecticut," has been published in the Popular Science Monthly for December, 1891, by the senior author.

All these previous studies have been chiefly concerned with the struc-

* Published by permission of the Director of the United States Geological Survey.
† Bull. Geol. Soc. Am., vol. 2, 1891, p. 416.

ture of the formation within its boundaries, which were examined only incidentally until especially studied in recent summers by the junior author. This paper is chiefly concerned with the results thus determined along the eastern boundary of the formation. Our problem is in effect: How closely does the present border of the Triassic formation follow its original constructional border, and how much has it been modified by deformation and erosion? This problem must be entered with a clear understanding of the results already gained regarding the structure of the formation as a whole, which are therefore briefly reviewed here.

## Geological History of the Region.

The Triassic conglomerates, sandstones and shales lie on a complex foundation of crystalline and metamorphic rocks which were greatly eroded before Triassic time. The unconformable relation of the two is wonderfully well displayed on the western border of the formation in a ravine west of Southington, some twenty miles north of New Haven. A belt of the old crystalline land area seems to have been depressed and submerged, and this belt as it sank continually received the waste from the more elevated parts. Thousands of feet of sediments were thus accumulated, the surfaces of successive strata having been frequently exposed to shallow currents, as is shown in ripple-marks, to sunshine, as testified to in mud-cracks, and to passing showers, as indicated by raindrop imprints. Fish swam in the clearer waters, where fine shales were formed; reptiles walked over the mud-flats, marking their paths by the so-called "bird-tracks," for which the valley is famous. The sediments were coarser near the eastern and western margins, where wave and current work were active, occasionally supplying bowlders up to several feet in diameter, while the contemporaneous deposits in the more open waters of the middle area were generally finer. We do not find any facts whose explanation requires the aid of glacial action. Vast volcanic eruptions interrupted the more quiet processes of sedimentary deposition by the intrusion of dikes and necks of diabasic lava, by the discharge of outbursting ashes, by the outpouring of broad lava flows, and by the intrusion of deep seated lava sheets. These lavas will be here referred to by the popular term, trap.

The materials accumulated may be summarized as follows: Resting on the crystalline foundation there are generally from 200 to 1,500 feet of bottom sandstones and conglomerates, beneath an intrusive sheet of trap about 650 feet thick; then follow from 5,000 to 6,500 feet of lower sandstones and conglomerates; 250 feet of an amygdaloidal trap sheet, sometimes with ashes and lava blocks, indicative of explosive eruption and called the anterior trap sheet; 300 to 1,000 feet of anterior shales and sandstones, including a black shale bearing fossil fish; 500 feet of heavy

trap, known as the main trap sheet, the other members of the series being named according to their position with respect to this dominating member; 1,200 feet of posterior shales and sandstones, including a second bed of fish-bearing black shales; 150 feet of posterior trap, and at least 3,500 feet of upper sandstones and conglomerates.

The chapter of deposition was brought to a close by an uplift which ended in giving the formation as a whole a faulted monoclinal structure with generally eastward dip. An unknown breadth of crystalline rocks was also disturbed on the east and west. This deformation was accompanied and long followed by erosion. It is manifest that no close relation can be expected between the dates of beginning and ending of this chapter of deposition and the dates of beginning and ending of any standard division of geologic time; hence the term Triassic is employed here rather as a makeshift term, following the usage of earlier papers, a departure from which would cause inconvenience, although the authors sympathize with Professor Russell's motive in introducing the non-committal term Newark as a general name for the red sandstone and trap formation of the eastern United States.

It is important to recognize that the erosion introduced by the monoclinal deformation has completed one cycle of destructional processes and has advanced well into another cycle. The constructional topography introduced at the close of Triassic deposition has been completely extinguished, the denudation of the first cycle even reaching to effective baseleveling and producing an extended peneplain of moderate relief over the adjacent crystallines as well as along the Triassic belt.

Whatever oscillations of level may have occurred during the later stages of denudation of the peneplain, they have not left significant topographic marks; but after it was developed there was a submergence of its southward margin, by which the sea was allowed to lap over it, and sediments bearing Cretaceous fossils were laid down in these encroaching waters. The inland extension of the Cretaceous submergence and deposition is not yet determined, although it is hoped that when the structure of the crystalline rocks of Connecticut is better understood the innermost Cretaceous margin may be discovered by means of the relations of revived and superposed streams and rivers.

At some later stage than the deposition of the Cretaceous cover on the border of the peneplain, and hence presumably within the limits of Tertiary time, a considerable northward uplift occurred, giving the old lowland an altitude of over a thousand feet in Massachusetts and further north, increasing the slope of the southward rivers and rejuvenating all their fading activities. At the same time at least a part of the submerged area, with the Cretaceous cover on its back, was raised above sealevel, and the rivers were presumably extended across the Cretaceous coastal plain to

the new shoreline. Thus introduced into a new cycle of erosion, the region has again been seriously denuded. Whatever cover of Cretaceous strata there was has been stripped off from New England, the edges of the retreating strata appearing now in a tame escarpment, cloaked with glacial moraines, on Long Island, while Long Island sound is the valley, now submerged, that usually occurs between such an inland-facing escarpment and the land over which the strata of the escarpment formerly extended.

During the Tertiary cycle of erosion the harder crystalline rocks east and west of the Triassic belt have been dissected by narrow valleys, of which the upper Farmington is the type in the western crystalline plateau of Connecticut, and of which the beautiful gorge of the Connecticut river, from Middletown to the Sound, is the type in the eastern plateau. These plateaus may therefore be said to have reached an adolescent stage of denudation. But in the intermediate belt of weaker Triassic rocks the surface is as a rule well reduced toward the present baselevel, and an extensive lowland separates the two crystalline plateaus. It is true that here and there the trap sheets and the harder sandstones and conglomerates have not yet been much consumed beneath the surface of the peneplain to which they were worn down in Cretaceous time; but as a whole the Triassic belt has acquired a distinctly past-mature, almost an old, expression. This expression was essentially reached before the earliest ice-sheet of the glacial period entered the region, and although a considerable amount of glacial erosion was then accomplished; although certain significant oscillations of level took place, and although broad sheets of stratified drift were laid down in the valleys, still all these changes are of minor importance compared to those by which the adolescent stage of the crystalline plateaus and oldish stage of the Triassic belt were reached.

The recognition of these successive chapters in the history of the region has required a general understanding of its structure, and the more minute interpretation of the trap ridges by which the Triassic lowland is interrupted has required a close study of the monoclinal faulting which introduced the post-Triassic cycle. But all this has not required any close knowledge of the relation of the former and present boundaries of the Triassic strata. This particular question is here discussed.

## Faults.

### *Faults in General.*

A few paragraphs may be allowed on the subject of faults in general, for the reason that some geologists have expressed a feeling that faults were an easy recourse for the explanation of perplexing difficulties, and that their existence was sometimes too lightly entertained. In order to avoid the just application of such a criticism to our work, we first

consider the general problem of faulting, briefly here, more fully in our own studies; we, second, examine carefully the facts and arguments on which our belief in the occurrence of faults is based; we, third, recognize a marked difference in the completeness of argument by which the various faults are defined, some examples reaching complete geologic demonstration, while other examples are hardly more than provisional geologic inferences.

Under the term, fault, we include a fracture of greater or less extent on which differential movement of the adjacent masses has taken place. Faults may be minute and clean cut, as often seen on joint planes in quarries; they may be of great dimensions and complicated structure, as known in our Appalachians and elsewhere. They are manifestly associated with different classes of strains; sometimes indicating an extension of the region involved, sometimes a compression, sometimes a lateral or tangential shearing. They are on the one hand associated with monoclinal folds, and on the other hand with overthrust folds. The plane of the faults may have any inclination to the horizon, and the movement of the adjacent masses may have any directions on the fault-planes. After the faulting, the fault-plane itself may be deformed or faulted, and the dislocated masses may be deeply eroded, even to baselevelling.

Faults are ordinarily recognized by some lapse of continuity in masses that were once continuous. This is variously determined. In the underground work of mining the fault-fracture itself may be encountered; the dissimilarity of the adjacent masses is then clearly demonstrated, and the occurrence of mechanical disturbance on the fault-plane is indicated by breccias and slickensides; but not once in a hundred times is a fault thus determined; and when thus determined, the visible portion of the fault-plane is perhaps less than a hundred-thousandth of its entire area. Faults are sometimes visible on sea-cliffs and in railroad cuts; they are occasionally seen on barren canyon walls, and still more rarely and intermittently on valley sides and in stream beds, but the actual visibility of a fault plane is a rare and local matter.

Most of the faults that have been represented on geological maps and sections are not known by the visible occurrence of their fractures. They are inferred from the lack of continuity of rock masses whose former continuity can be reasonably postulated. The safety of such inferences depends chiefly on the distinctness of the rock masses concerned, on the certainty of their former continuity across the fault-line, on the impossibility of explaining their present discontinuity by other means than faulting, on the closeness with which the fault-line may be traced, and on the association with it of various minor indications of mechanical disturbance.

*ELEMENTS OF A FAULT.*

When the field worker is driven to believe that a fault traverses his district, it is an aid to further study to have clearly in mind all the facts that should be determined before the whole history of the fault is unravelled, just as the astronomer on discovering a comet is aided in his next work by knowing just what facts must be determined in order that the movements of the comet can be recalled or predicted. These facts are called the elements of the comet, and the same term may be profitably applied to faults. Regarding faults, it is desirable to search first for such facts as may be visible at the surface of the earth. Chief among these is the fault-line, as indicated by the margins of adjacent formations. It may be straight or curved, simple or branching; it should be followed from end to end. Occasionally the fault-plane itself is locally visible in streams, cliffs or cuts. When possible, the hade or departure of the plane from the vertical should be determined. This may be locally accomplished where the plane is directly visible. It is sometimes determined in a larger way when the line of the fault leads over hills and valleys. The mechanical character of the fault should be studied as indicated by the

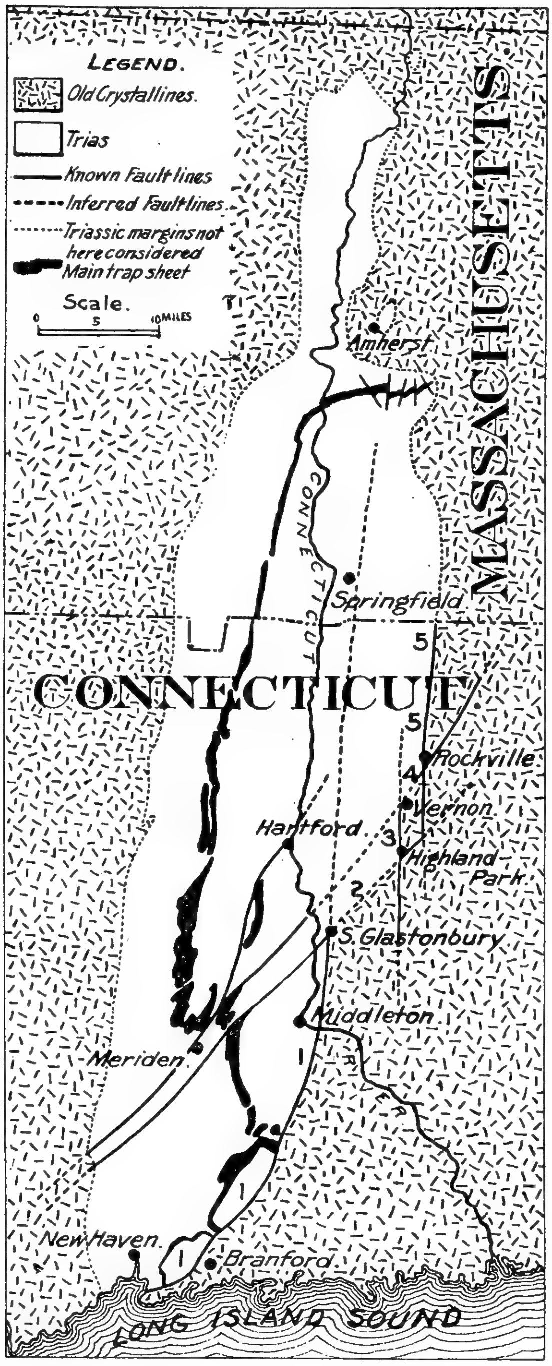


FIGURE 1.—*The Connecticut Valley Triassic Area.*

features of the fracture, when visible, or by the minor deformations in adjoining rock masses. The displacement caused by the faulting should be measured at various points along the fault-line, and the direction of

movement on the fault-plane should be discovered if possible. The relation of the fault to the existing topography is an important matter, this being frequently so prominent that it becomes the chief guide in tracing the fault-line in a preliminary survey.

The surface elements of a fault having been determined, there are elements connected with its past history that need attention. Its date of occurrence, its rate of movement, its cause, including the reasons for its location in one place rather than in another; its effect on the topography at the time of its production, and its effect on the subsequent processes of denudation, ending with the development of the existing topographic features.

It is hardly necessary to state that as a rule there is no opportunity for the determination of most of these elements of a fault; yet none the less should they be borne in mind and patiently searched for. The recent discovery of the long hidden "secret of the highlands" of Scotland, of the overthrust faults in the southern Appalachians, and of the mechanical conditions of the processes of faulting in folded structures are strong encouragements to the success of similar studies elsewhere.

## Deformation along the eastern Boundary of Connecticut Triassic.

### *GENERAL ACCOUNT OF THE EASTERN BOUNDARY.*

We have been led to the conclusion that the entire eastern boundary of the Triassic formation in Connecticut is defined by fault-lines—a combination of several intersecting faults, rather than a single irregular fault. As indicated on the map, figure 1, the inferred faults may be divided into two sets, those of one set trending about north and south, and represented by three members; those of the other set trending northeast and southwest, and including two members. All five faults are believed to extend beyond the parts of the border line that they determine into the area of the crystalline or Triassic rocks. In the following description the faults will be referred to by numbers, as on the map; the first (with a rather irregular course), third and fifth belonging to the meridional set; the second and fourth belonging to the oblique set. The four angles in the border line, formed at the successive crossings of the five faults, are distinctly marked in the field, and will be referred to as the Glastonbury, Highland Park, Vernon, and Rockville corners.

### *EVIDENCES OF FAULTING ALONG THE BOUNDARY.*

*Absence of direct Evidence.*—With trifling exceptions, referred to below, the lines and planes of the bordering faults are nowhere visible, either along the boundary of the formation or along their extension elsewhere. Within the Triassic area certain small branch faults associated with the faults of the oblique set are exposed in quarries and streams, but none

of these have movements of considerable measure. In spite of this invisibility, we confidently believe in the existence of the marginal faults. They need not be more doubted than many others elsewhere whose existence is satisfactorily established on indirect evidence.

*Discontinuity of Triassic Strata.*—Although the faults themselves are nowhere seen, good evidence of their occurrence is not wanting. On approaching the eastern boundary of the formation, south of the Glastonbury corner, it is found that the Triassic strata are abruptly terminated against the crystalline terrane. This is best seen along the first fault-line, especially in its southern part, where it turns to a somewhat oblique course. Here various recognizable strata of the series, either aqueous or igneous, may be easily followed along their strike by repeated outcrops or by the continuity of essential topographic features, tested by occasional outcrops, and in many successive instances the border of the formation runs at a strong angle with the strike of its members. It is easily conceivable that such a relation might follow from the erosion of a series of strata unconformably overlapping an inclined foundation; but this possibility is excluded here by reason of the directness of the border line, in spite of repeated changes in the strike and dip of the bordering strata. It is most impressive to follow the sweeping curves of Pond and Totoket ridges,* formed by the main trap sheet, whose great extension is so well proved, and perceive its obedient termination as it approaches the border line. Its strength does not weaken; it is still a heavy flow of lava, as strong a ridge-maker near the border as away from it; it shows no signs of thinning, as if toward its original margin; it abruptly stops. This is but a repetition of the lesson of the Meriden district, where the ridges formed on this heavy lava flow so submissively disappear on approaching the invisible, but dominating fault-lines.

As with the ridges of the main trap sheet, so with the minor ridges of the posterior trap sheet and the valleys of the anterior, posterior and upper shales, sandstones and conglomerates. On the ground, where the successive localities are far separated and out of sight from one another, these facts are slowly perceived, but when presented on a map it is very manifest that the curved belts formed by the successive members of the formation, so systematic within the Triassic area, are all cut off at the border as if by some gigantic shearing tool.

It is not only that the edge lines of the several members of the Trias are cut off at the border, but the dip lines must by inference be cut off underground. If we pass southeastward through the middle of either the Pond Rock or the Totoket crescent, we discover a strongly marked monoclinal structure, with dips averaging twelve or fifteen degrees, passing upward from the lower sandstones and conglomerates, through the

* The curved southern members of the main trap sheet, figure 1.

anterior trap sheet, the anterior shales, the main trap sheet, the posterior sandstones and shales, the posterior trap sheet and a greater or less thickness of upper sandstones and conglomerates. It is perhaps possible to invent a system of very special conditions by which the monoclinal strata can be supposed to end underground against a great cliff or steep land-slope, at whose base lay the water body in which they were accumulated; but the essential conditions of this invention are so peculiar, so complicated, and so little in accord with the other features of the region that they are soon discarded; hence the dip lines by reasonable inference, as well as the strike lines by observation, must be interpreted as terminating against a fault. On the other hand, the northern part of the border has few neighboring Triassic outcrops. The evidence of faulting is less distinct there than further south; yet on making a general section on true scale across the Triassic lowland it is difficult to account for the disappearance of the strata unless cut off by a marginal fault.

*Fault-line Valley.*—A narrow, meadow-like depression, followed more or less by streams, but here or there rising in low divides, is traceable more or less continuously along the boundary line between the adjoining outcrops of Triassic and crystalline rocks. There is no reason for this valley except the occurrence of a belt of shattered rock, such as is commonly produced on strong fault-lines. Sometimes the depression or fault-line valley is a quarter of a mile in width, being then, as a rule, adjoined by the weaker members of the Triassic series. Sometimes it is merely a narrow pass between close approaching slopes on either side; this being the case where the harder Triassic members confront the bolder crystalline slopes. The change of the depression from one form to the other is comparatively systematic, as may be seen near the northeast end of the Totoket crescent. The crystalline slope here maintains a fairly regular course on the eastern side, but the western side of the depression varies with the resistance of the Triassic member ending upon it.

North of the Connecticut river the marginal depression, like the other features by which the fault-lines are located, is much less distinct than to the south. The absence of the marginal valley is presumably an expression of the two prevailing features thereabouts; relatively weak Triassic rocks, allowing an effective baselevelling of the whole area and a plentiful distribution of drift, almost obscuring the rock topography.

*Associated Dislocations.*—The disturbances which we associate with the production of the greater marginal faults are found in both the Triassic and the crystalline areas. The former will be mentioned first.

In the Pond Rock crescent the ridge formed by the main trap sheet is repeatedly offset by small faults as it approaches the crystallines at its southern end, each offset being marked by a gap or notch in the ridge.

It is to the weakness thus engendered that we attribute the disappearance of the anterior trap ridge in the southern part of this crescent. The southern end of the posterior trap ridge is much obscured by heavy drift, and nothing can be said of it; but near the middle of the Pond Rock crescent, along the Triassic border in the village of Branford, there is a second posterior ridge, and this has already been interpreted in earlier papers as a reappearance of the same trap sheet that forms the first posterior ridge. A close examination of the ground does not, however, confirm the relatively symmetric reversal of dip indicated in earlier figures, and hence it is concluded that this second ridge is formed of large fragments or blocks of the posterior trap sheet that were caught in the fault. The varying attitude of the trap sheet, as inferred from the position of its dense under surface and its vesicular upper surface, as well as the plentiful breccia of angular trap fragments with sandstone matrix, give support to this conclusion. Outcrops in this neighborhood are, however, very few. Further north, near Middletown, there is much irregularity of dip and strike in the sandstones near the margin, such as never occurs within the area of the formation except in the neighborhood of fault-lines. North of Glastonbury the marginal outcrops of Triassic strata are so rare that no sound conclusion can be based on them alone.

*Alteration of Crystallines along the Border.*—The old crystalline rocks present characteristics along the meridional part of the Triassic margin which are not common to these rocks elsewhere. The fact that the general strike of the old gneisses and schists is about northeast and southwest, thus giving a considerable angle of intersection with the meridional fault-lines, makes it possible to associate changes in the characters of rocks along their strike-lines with the explanation of the border line itself. The greater development of chlorite along the border line is a marked feature throughout. Microscopic examination shows that the crystals of different minerals are commonly broken. In many places the simple gneissic or schistose structure has been lost, and the rock appears twisted and broken. The rock thus affected may still remain in this crushed condition, presenting a loose fault breccia, as at the quarry for road-metal at South Glastonbury; or it may be re-cemented into an exceedingly tough rock by quartz or chlorite, or sometimes by barite. The rock thus formed seems to be much more enduring than many of the unmodified members of the old crystallines, yet special search among the Triassic conglomerates has failed to reveal its presence; hence it is thought to be of later origin than the conglomerates. The alteration of the crystallines has been made out clearly only along the meridional portions of the Triassic border. It is less distinct along the oblique portions. This, however, might be expected, even if faults occur there, for the reason that movement near the plane of foliation would

cause less alteration than movement transverse to it. It would be more difficult also to demonstrate that the change was due to faulting, because any change that occurs might be attributed to a change in the character of successive folia across the strike rather than to a change in a single relatively continuous portion of the crystalline mass along the strike.

*Association of marginal and internal Faults.*—The internal faults, as those which are found within the Triassic area may be called, have been successfully worked out along the trap belts, whose numerous dislocations give complete demonstration of their occurrence. In the district about Meriden there are two chief faults—one separating Higby mountain from Chauncey peak, the other separating Lamentation mountain from the ridges of the Hanging hills. The throw of these faults is estimated at 2,000 and 3,000 feet respectively. Their course is about northeast and southwest, though the latter fault splits near Berlin; one branch, having a throw of 1,000 feet extends northeastward, the other branch turning to the north. After their discovery by means of the dislocations in the trap ridges, they were traced in both directions by means of the local deformation that they caused here and there in the bedded rocks, and they have now been extended with some confidence to the crystalline areas both northeast and southwest of the locality in which they were first detected, by means of dislocations and breccias along their lines. It is therefore regarded as a matter of much significance that the oblique courses of the eastern border, determined by the second and the fourth faults of the marginal series, fall directly in line with the northeast extension of these two great internal faults. The essential accordance of these members of the internal and external faults, although unlike in appearance and of independent discovery, but both explicable as common effects of a single kind of process, leads to much confidence in our conclusions.

*Additional Evidence from the separate Faults.*—The general evidence above stated is sufficient to demonstrate faulting along part of the contact for the two formations in question; still, more evidence is desirable, and to get any quantitative idea of the faults, is necessary.

Fault number 1 is bordered by a part of the Triassic area which has been warped into three shallow, saucer-like folds. Their diameters are five, seven and fifteen miles respectively, beginning at the south; these may be called the Pond, Totoket and Middletown saucers; but these saucers are not complete, only their western halves are visible. About one-half of what must have been their original area, had they been symmetrical, would belong east of the border line where we now find the gneisses and schists. Thus what may be termed the broken edges of the saucers abut against the contact line, presenting the Triassic rocks with strikes varying from parallel with the contact line near the middles

of the saucers to perpendicular at the saucer rims. These saucer-like half-synclines have anticlinal separations which have been eroded; the rock series was originally continuous throughout, and now the edges of this rock series, repeated in reverse order six times, abut against the old crystallines.* This in itself is a conclusive argument for a fault contact along this part of the line, and, furthermore, affords data for computing the amount of dislocation. The throw must equal at least the thickness of Triassic rocks between the lowest and highest beds found abutting against the line; but such a measurement does not include the lowest beds of Trias which cannot be denied to exist on the eastern side of the Triassic basin though not exposed at the surface, and surely these beds as well as those measured have been eroded from the uplifted crystalline foundation on the east side of the great fault-line. Reckoning these lower sandstones at one-half the thickness on the eastern side that they have on the western (the formation thinning on the eastern side because nearer the conceived shoreline of the old Triassic basin), the minimum throw of the fault in the central part of the Totoket saucer is 9,000 feet; thirteen miles further north, in the central part of the Middletown saucer, the throw is 8,000 feet. Thus the amount of dislocation seems to decrease on going northward, and other sections confirm this idea.

In the above explanation it has been assumed that the folding preceded the faulting, though it might be urged that the semblance of folding was given as a result of differential movement on the fault-line. This would necessitate a differential throw in the two southern saucers of over 4,000 feet within a lateral distance of about 16,000 feet, and this process twice reversed or four times repeated. This supposition seems, therefore, less probable than the assumption that the folding and faulting were successive.

Fault number 3 has one important locality giving evidence of faulting. At Highland Park paper mill, Triassic conglomerates were found not far distant from the old crystallines, and a trench was dug to show the character of the contact. The conglomerates were found to be less compact near the contact, becoming so loose that they were easily worked with a pick. Sandy layers at the contact gave a dip of 45° to the west, showing a strong drag movement. The small surface of the contact that was uncovered had a dip of 55° to the west and a strike north and south. The crystalline rocks at the contact were much shattered and decomposed, so that they also were easily worked with a pick. Twenty to thirty feet away, however, though much contorted, they have been so consolidated by the vein-forming process that they rise in a bold bluff

* On the map the Pond mountain and Totoket mountain saucers are well outlined by the main trap; the north side of the Middletown saucer is bordered by the posterior trap which is represented near the margin at South Glastonbury, but is not here shown.

over which the Highland Park waterfall descends. At this locality there are indications of a small preglacial, marginal valley now filled with drift, but the section is too obscure to make a positive statement. At the northern end of this fault-line the crystallines are much shattered and to some extent recemented. The facts here recorded are accepted as conclusive evidence of faulting along this division of the marginal line. This fault is considered to have a much smaller value than number 1, as will be explained later.

Division number 5 is lacking in evidence that shows the direct relation of Trias to old crystallines. However, the border metamorphism of the old crystallines is well marked, and at a small mill two and a half miles northeast of Ellington there is an excellent brecciation of the crystallines which has resulted in considerable decomposition. The fact of faulting is unquestionable, but the post-Triassic date has to be inferred from analogy with divisions 1 and 3. It is a satisfaction to record that after the work had been carried to this stage comparison with the unpublished work of Professor Emerson in Massachusetts showed entire accordance in results.

Fault number 2, as previously stated, has not been established along the contact line, but both to the northeast in the crystallines and southwest in the Trias the evidences of a fault-line are good. In the crystallines near the border line the projection of this fault-line first follows a stream valley and then is covered by drift until Bolton Notch is reached, distant three miles from the margin. Here along the cut of the New York and New England railroad numerous fault-breaks are noted having strikes in a northeast direction. The breccias seen belong to faults of small throw; the greater lines of break are probably concealed by erosion. Turning in the other direction to the Triassic area, the next to largest fault identified, having a throw of about 2,000 feet, has been traced from the old crystallines on the western side of the basin to South Glastonbury, a distance of 26 miles. The direction of the fault is about northeast and with little variation. It does not seem unreasonable to continue the line of dislocation northeastward, connecting with the fault indications at Bolton Notch. Further reason for believing in this extension will be given when the measurement of the faults is explained.

The inference with regard to fault number 4 is based upon evidence similar to the above. The northeast extension of this fault is indicated in the northeast part of Rockville in a small quarry by breaking and slickensiding. The line follows a general valley depression in the crystalline plateau, and is indicated by local cortortion and alteration of the crystallines and by breccias. These indications have been traced northeastward for eight miles from the border. The continuity of this fault is

better shown in the crystallines than in the Trias, for although the internal fault with which number 4 is supposed to be continuous has a throw of about 1,000 feet and is a branch of the great Lamentation fault, yet where last identified in the Trias it is a dozen miles from the corner at Vernon. The span of fifteen miles from one point of evidence to another may test one's credulity severely, but if the line be thus drawn it is found to coincide in direction with the established parts, which have a total length in crystallines and Trias of about 35 miles; furthermore, its nearly parallel relation to number 2 is maintained. The two lines diverge very little as they continue northeast. As in the case of number 2, an explanation of the measurement of the two fault systems will strengthen belief in the inference of their occurrence.

*Another explanation of the Contact Line considered.*—It might be argued that the marginal line in question is one of continuous fault of irregular trend instead of a combination of five faults, as urged in the preceding section. Let us consider the difficulties of this idea. First, the irregular shape of the line, with its four angles at South Glastonbury, Highland Park, Vernon and Rockville, is in opposition to the generally straight trend of faults within the Trias. It is true that the southern part of number 1 is somewhat irregular, but there are no such sharp changes as at the corners noted above. Second, why should two of these abrupt changes in direction happen to come just where Triassic faults reach the margin? Mere coincidence would be extraordinary. Third, if so great a fault as number 1 passed along parts 2 and 4, even though coinciding in strike with the strike of the crystalline rocks, field observations should have given unquestionable evidence of movement or metamorphism. Fourth, it seems possible to distinguish a relation between the values of 1, 3 and 5 by the amount of crushing and metamorphism that has taken place. Thus 3 and 5 are noticeably lines of lesser disturbance than 1, and 5 would seem to be somewhat greater than 3.

*Measurement of the Faults.*—With the above difficulties in the way of the one-fault idea, if we can strengthen the combination plan by an hypothesis of effective quantitative working, we may reasonably give it the preference. Fault number 1 we conceive to continue northward from South Glastonbury. South of this point the crystallines comprise the surface rocks on the east side of the line, and from these crystallines has been eroded all the Trias that once extended there, and some of the crystalline foundation as well. Why do the crystallines not continue at the surface north of this point? Because an oblique fault, with a downthrow of about 2,000 feet on the northwest side, intersecting here, has brought the Triassic foundation plane below the present Triassic level of erosion. The present Triassic level is about 600 feet below the level of

the crystalline plateau; therefore its foundation plane is more than 600 feet below the plateau surface. The fact that a fault of this value could throw down the foundation plane to its present position indicates that, as a maximum amount, less than 1,400 feet (2,000 — 600 +) of crystalline rock in the vicinity of South Glastonbury have been eroded since Triassic times. Correspondingly, the Triassic foundation plane must be less than 1,400 feet below the present Triassic surface, if it be considered that only a small amount has been eroded from the crystallines to produce the present plateau.

But how far east does the influence of the northeast fault go? We should suppose until the angle of slope of the foundation plane brought the undisturbed sedimentary Triassic contact to the surface of erosion. This would doubtless be at no great distance, for the coarseness of the conglomerates along the eastern marginal line indicates nearness to a Triassic shore; but another meridional fault, number 3, with upthrow on the east, crosses the old basin and uplifts the foundation plane so that the Trias has been eroded, and gives a fault margin from Highland Park to Vernon instead of a sedimentary contact farther east. Can any idea of the value of this fault (number 3) be obtained? It must have a minimum throw equal to the distance of the Triassic foundation plane below the Triassic surface plus the elevation of the highest part of the adjacent crystalline plateau above the Triassic surface; the latter elevation is 600 feet; the former distance is between 0 and 1,400 feet. The minimum is therefore over 600 feet; the maximum might seem to be indefinite, but the next fault helps to define it as less than 2,400 feet.

Our combination of faults has carried us to Vernon, where fault number 3 is supposed to continue northward, and should have crystallines along its east side. As in the case of number 1, at South Glastonbury, the Trias appears instead, this time brought down by a fault of about 1,000 feet. If a throw of this value can bring down the Triassic foundation plane below the present surface, the maximum throw of fault number 3 must have been less than 2,400 feet (1,000 + 1,400 —).

As before, we should follow eastward to find the line where the Triassic sedimentary contact should come to the surface, but before it is reached we come to another north-and-south fault, number 5. This line bounds the Trias even into Massachusetts, so that a sedimentary contact on the eastern margin of the Connecticut Trias cannot be found at the surface. For this last fault we can only assign a minimum value of 900 feet plus, which is something more than the difference in elevation between the levels of the Triassic surface and the highest points of the crystalline plateau. If we may judge by erosion, brecciation and metamorphism, this line was one of greater dislocation than number 3.

In figure 2 a diagrammatic representation is given indicating our conception of the complicated part of the boundary line, looking at the district from the north, so that all the steps are in full view, and picturing the contact planes, both of sedimentation and faulting, of the two formations. The solid block may be considered as composed entirely of old crystalline rocks; an imaginary cap fitting this block would represent the original Trias. The numbers given to the different fault-lines are indicated on the diagram.

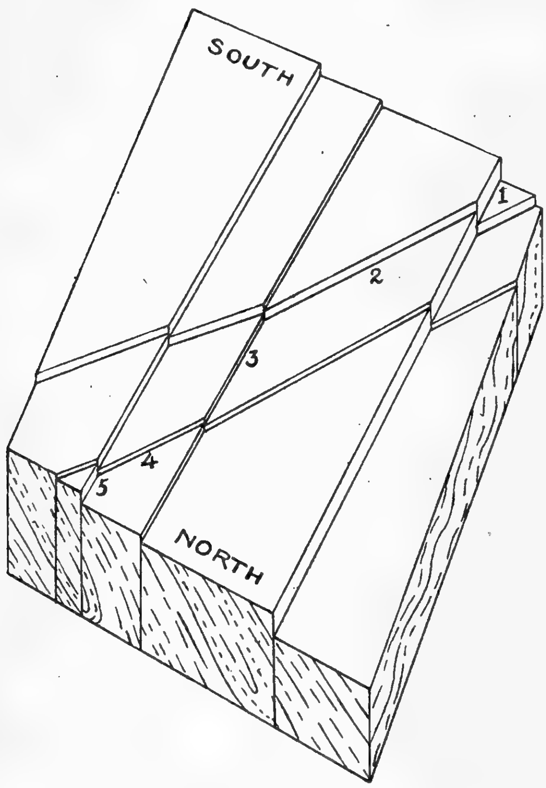


FIGURE 2.—*Stereogram of Cross-Faults of the Eastern Boundary of the Connecticut Trias.*

*FINAL CONSIDERATIONS.*

The hypothesis of a combination of faults is thus seen to correspond with the facts of distribution of formations and of faults. No evidence is known that contradicts the hypothesis in any way; it may seem weak because of a partial lack of evidence. It may at first thought be considered a suspicious accident that the level of the present erosion surface should fall so nicely between the limits within which it is possible to get the evidence revealed in the district between South Glastonbury and Rockville; yet one can see on considering a detailed map that were the erosion surface relatively several thousand feet lower or higher than it now is the demonstration of the structure would be equally clear. That the hypothesis offers a rational explanation of the widening of the Triassic to the north is in its favor.

A point of interest connected with the demonstration is that the basal members of the Trias are brought up on the eastern side of the basin. It of course occurs to one to identify these rocks with those on the western side. As yet no characteristic beds are known on either side, so comparison cannot be made.

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# PLEISTOCENE PROBLEMS IN MISSOURI *

BY J. E. TODD

(*Read before the Society December 29, 1893*)

CONTENTS



## Introduction.

As one portion of the country after another has had its glacial geology cleared up in recent years by the enthusiastic research which later theories have inspired, doubtless more than one glacialist has turned his eyes toward Missouri, which exhibits a wider area of extramorainic drift than is found in any other state, and shows northern drift at the remotest point from its original source, unless, possibly, Kansas takes the palm in these respects. It is, therefore, with satisfaction that I attempt a brief

* Published with the permission of Arthur Winslow, State Geologist of Missouri.

exposition of the facts which I have been able to discover in about three months' field work in connection with the Missouri Geological Survey. I regret that I could not bring the work nearer completion, but as I shall not, at least for some time, be able to carry it farther, it seems best to offer this report of progress for consideration, comparison and criticism.

As is well known, the field is not a new one. Years since, various valuable notes were published in the earlier state reports on the Quaternary formations. I have been pleased to find such statements uniformly reliable, so far as they go. Their deficiencies to a later student arise mainly from two causes. The older formations in early days were considered much the more important and interesting, while later formations were of little significance; and again, owing to imperfect views, formations of widely different origin were sometimes associated in the same definition. For example, Professor Swallow, on page 77 of the Second Annual Report, states that "the bowlder formation abounds in all parts of the state north of the Missouri, and exists in small quantities as far south as the Osage and Meramec." In this he includes with the northern glacial drift what Broadhead later and more correctly calls "local drift," and which has since been shown to be in part as old as the Carboniferous. Broadhead's statement that the drift is limited by the bluffs on the south bank of the Missouri is, I find, with a very few exceptions, correct.

## THE PREGLACIAL FORMATIONS.

### *GENERAL GEOLOGIC AND TOPOGRAPHIC FEATURES.*

In considering the preglacial formations a brief outline of the general topography of the region they occupy will first be given. Attention is particularly directed to that part of the state of Missouri north of the Missouri river, for the Pleistocene formations are but sparsely distributed south of that stream. The region is a plain sloping to the south and east, into which the larger streams have cut from 250 to 300 feet. Its height at the northwestern corner of the state is over 1,200 feet above sea-level. It descends toward the Missouri to an altitude less than 1,000 feet near Kansas city and to about 700 near the Mississippi at Palmyra.

The Ozark uplift occupies a little more than the southeastern quarter of the state. Its northern boundary leaves the Mississippi near the mouth of the Meramec, passes northwest to the Missouri, thence westward a little north of that stream to the mouth of the Maniteau and onward to the vicinity of Sedalia. It there extends in an anticline running north to the Missouri in eastern Saline county. The western boundary of the uplift follows the trend of this anticline to the southwest and afterward to the south. The Ozark uplift, as thus outlined, is composed mainly of Silurian rocks. Along the northern margin of the uplift is an edging of Devonian rocks, dipping gently to the north. Separated from the Ozark

uplift is another area of Silurian rocks extending along the northeastern border of the state near the Mississippi. These are separated from the Ozark uplift by the Alton fault. These also are overlain by Devonian and Lower Carboniferous rocks dipping to the north and east. Surrounding these slightly elevated areas are the more horizontal Carboniferous formations almost undisturbed from their original deposition in the sea.

The erosion of these formations, before the deposition of the Pleistocene brought out certain topographic features. By the removal of the softer shales and sandstones the firmer limestone areas were left as ridges, the more notable of which are found in the western part of the state and have a prevalent northeast trend. One crosses the Missouri near Lexington, another at Independence, another, less elevated, crosses a little west of Leavenworth, and a fourth near the mouth of the Nodaway.

### *THE BOWLDERY DRIFT.*

*Its Character.*—The character of this deposit, being of secondary importance to our purpose, we shall but briefly describe it. It presents the usual features of till or unstratified pebbly clay, and shows the usual bluish appearance where it occurs to considerable depth. It nowhere presents the gravelly and very stony character which it sometimes displays farther north. It is rarely more than forty feet in thickness and more frequently is less than five, and over considerable areas consists simply of a sprinkling of northern pebbles. It contains numerous crystalline pebbles and bowlders which are frequently striated. The upper portion becomes gradually less pebbly and acquires more of a reddish color. This is more noticeable toward the west. Below it often passes insensibly into an accumulation of local bowldery clay in which the nodules of chert and limestone abound. Above it passes abruptly into the loamy clay, which will be described further on. So far as yet discovered, it shows no basins or knobs which so commonly occur in glaciated regions; but, on the other hand, its surface is very even wherever it is clearly undisturbed. From erosion of the country in the vicinity of streams and valleys this formation has been creeping and slipping, losing in great degree this horizontal position. Masses of it have in a few cases even descended to the level of the present streams. It nowhere presents beds of gravel or sand. In fact they are sought for almost in vain through northern Missouri, except in the vicinity of present streams and at low levels, and even in such localities are found but sparingly. The drift is most thickly deposited in the northwestern corner of the state, extending as far south as Saint Joseph, and also along the divide between the Chariton and the streams flowing into the Mississippi. It should be remarked in this connection that the extreme northern part of the state

has not been fully explored. No distinct traces of a forest bed or old soils have been found in the region under consideration. Even Mr McGee, who may be considered an expert upon this point, in his examination of Macon county* failed to discover any.

Striæ are rarely found on the underlying rock. So far as yet discovered they are found only in the vicinity of the Missouri river. They are found a little north of Saint Joseph in small patches about 125 feet above the Missouri, in directions south and south 26 degrees west. Some were reported from Parksville, but have not been examined. Near Harlem, opposite Kansas City, fine examples were found on a ledge about 130 feet above the level of the river, having the directions south 7, 19 and 24 degrees west, and others very clearly shown south 51 degrees east. In the eastern part of Kansas City, a slight scratching of the rocks was found about 100 feet above the river, with the direction south and south 6 degrees east. Another locality, about 7 miles south of Glasgow, was reported to me by the late Professor S. H. Trowbridge as being about 100 feet above the river and showing directions a little west of south and south 20 to 25 degrees west. I believe Professor J. W. Kilpatrick reported upon this locality in "Science" two or three years ago.

*Distribution of Bowldery Drift.*—The bowldery drift covers the whole surface of the state north of the Missouri river, with few exceptions hereafter to be stated, and very unimportant narrow areas south of this stream and also along the western bank of the Mississippi. The exact limit of the drift has been quite carefully studied on account of its significance; still two obstacles have prevented its exact determination: one, its vicinity to the Missouri and consequent removal by erosion; the other, the fact that it is often deeply buried under the loess. The drift usually thins out toward the edge, although in a few cases it is quite well developed near the border, as north of Hibernia and in the vicinity of Warrenton. Where the border approaches higher land it rises slightly above its general surface farther north.

The following table presents the occurrence of northern erratics on or very near the margin. The altitudes are merely close estimates derived from barometric notes and reference to the topographic map of the region published by the United States Geological Survey.

| *Locality.* | *Altitude above Missouri.* | *Altitude above the sea.* |
|---|---|---|
| Kansas City, Jackson county, top of bluff near Ferrier avenue | 100 | 825 |
| Three miles west of Sibley, Jackson county | 100 | 800 |
| Three miles south of Sibley, Jackson county | 100 | 800 |
| Lexington, southwest of town, Lafayette county | ... | 800 |

* Geology of Macon County, Trans. St. Louis Acad. Sci., vol. 5, p. 305.

| *Locality.* | *Altitude above Missouri* | *Altitude above the sea.* |
| --- | --- | --- |
| Waverly, southwest of town, Lafayette county | 80 | 730* |
| Salt Springs, northwest of railroad bridge, Saline county | ... | 730* |
| Marshall, east of junction, top of till, Saline county | ... | 730* |
| North of Blackwater, Cooper county | ... | 820 |
| Billingsville, Cooper county | ... | 700* |
| East of Rocheport, Boone county | 200 | 770* |
| Bluffs thirteen miles south of Columbia, near mouth of Bon Femme, Boone county | 300 | 850 |
| Hibernia and two miles south, Callaway county | 330 | 860 |
| North of Saint Aubert, at various levels up to five miles north of Saint Aubert, Callaway county | 300 | 830 |
| Five miles northwest of Portland, Callaway county | ... | 840 |
| Danville, Montgomery county | ... | 830 |
| Four miles south of New Florence, Callaway county | ... | 850 |
| Two-thirds of a mile south of Warrenton, Warren county | ... | 850 |
| Tuque, seven miles south of Wright City, Warren county | ... | 875 |
| New Melle, seven miles south of Wentzville, Saint Charles county, about | ... | 800 |
| Gilmore, Saint Charles county | ... | 600 |
| Near Troy, west of Cuivre river, Lincoln county, about | ... | 675 |
| Two miles east of Briscoe, Lincoln county | ... | 800 |
| Three miles east of Silex (Auburn), Lincoln county | ... | 825 |
| Cyrene, Pike county | ... | 845 |
| Bowling Green, Pike county | ... | 880 |
| Three miles east of McCune's, Pike county | ... | 825 |
| Near Hannibal | ... | 675 |
| Palmyra | ... | 650 |

### *THE LOESS OR LOAMY CLAY.*

*Its Character.*—Of this we need say but little. Its typical development has been often described and is most marked in the vicinity of the larger streams. The fact that it changes its character has not been so commonly recognized. Professor Salisbury, in his report on Crowley ridge, Arkansas, has called attention † to the fact that it becomes more clayey away from the principal streams, and it should also be added that its composition varies according to the formations around it. Its clayey form is sometimes of a reddish cast, as, for instance, in the ridges in the western part of the state, but more frequently, in central and eastern

* Those marked with a star are in an old channel of the Missouri.

Professor Broadhead, on page 22 of the Missouri Geological Report for 1873–'74, reports the finding of "quartzite and greenstone" pebbles in a heavy deposit of gravel "in Saint Louis county, three miles north of Glencoe." He kindly directed me to the place, and after spending several hours examining the deposit and its surroundings I concluded that I could find nothing of northern or crystalline origin. Moreover, examination of several favorable exposures in the eastern part of the county confirmed me in my conclusion that the region is truly driftless. The gravel appears to be of older origin than the Quaternary.

Professor Meek reports that a granite bowlder eighteen inches in diameter was found in the southern part of Morgan county, which is certainly a puzzle. Missouri Geol. Report, 1855–'71, p. 139.

† Arkansas Geol. Rep., vol. ii, 1889, p. 226.

Missouri, it is of a lightish and light gray complexion. It very closely resembles, if it is not identical with, the white clays described by Mr Leverett as found in Indiana and southern Illinois.* This variety resembles the residuary clays quite common in sub-Carboniferous and Silurian areas, and also a clay sometimes underlying the drift in north-central Missouri. Mr McGee states that the formation which he calls "upper till" in southeastern Iowa is the equivalent of the loess.† I have not been able to distinguish his "upper till" from this gray loamy clay.

*The Limit of the Loess and associated Deposits.*—One of the first things I discovered in studying the loess at Kansas City, where it is finely developed, was the fact that there is a higher loess and a lower loess. The latter is the deep silt covering of a high terrace which rises 125 to 150 feet above the Missouri and is confined to its near vicinity.‡ The former is that which caps the unmodified bowlder-clay where it occurs, and covers in some form all the uplands north of the Missouri river, as well as considerable areas to the south. The lower formation will be considered later, under the head of terraces.

For several reasons, no less prominent in Missouri than elsewhere, it is almost always difficult to determine the limits of the loess No beach lines have been found. Topography and depth of deposit are in many places the most obvious means of determining the margin. Not only does the loess resemble the adjoining residuary clays and loams, but the two are apparently intermingled. The loess-covered plain not only covers northern Missouri, but all Iowa outside of the moraine and Nebraska to its northern boundary and as far west as Aurora, Nebraska, and Salina, Kansas. Its southern boundary in Missouri may be given as follows:

| *Locality.* | *How marked.* | *Altitude above sea.* |
|---|---|---|
| Kansas City, Jackson county | Character, depth and topography | 950 |
| South of Lake City, Jackson county | " " | 925 |
| West and southwest of Sibley, Jackson county | " " | ... |
| Southwest of Lexington, Lafayette county | " " | 918 |
| Near Mayview, Lafayette county | " | 890 |
| South of Mayview, Lafayette county | " | ... |
| Southwest of Brownsville, Saline county | " | 800 ? |
| South of Hughesville, Pettis county | " " | 850— |
| Near Pilot Grove, Cooper county | " | 825± |
| Southeast of Billingsville, Cooper county | " | 825± |
| North of Prairie Home, Cooper county | " " | 83)± |
| Near Jamestown, Moniteau county | " | 850± |

* Am. Geologist, vol. 10, p. 18.

† Geology of Macon County, Trans. St. Louis Acad., vol. 5, p. 317.

‡ Cf. R. E. Call, Crowley Ridge, Ark. Geol. Rep., vol. ii, 1889, p. 41, where he recognizes a later and lower loess, though he does not find it in terrace form.

From this point the margin seems to have been in the present trough of the Missouri, for all flats north of there are more or less covered with it, while the heights south rarely show it. This relation obtains at least to the east line of Callaway county. It has not been clearly recognized on the high swells and knobs in Montgomery and Warren counties. It is certainly not to be found on the knobs in Pike and Lincoln counties. A deposit closely resembling it, if not contemporaneous, covers levels in Saint Charles and Saint Louis counties up to 150 to 200 feet above the Missouri. Its southwestern boundary in Saint Louis county is not far from the Creve Cœur branch of the Missouri Pacific railroad. It does not overtop Grays summit, though very near it. Its limit in this portion—that is, in Montgomery, Warren and Pike counties—may be said to correspond approximately with that of the drift, though rising perhaps 25 to 45 feet higher and extending correspondingly farther where the topography permits.

It should stated, however, that as the margin of the drift declines very much along the Dardenne and Cuivre rivers, so also with the loess or gray clayey loam. The two do not lose their relations to each other, though they cover the hilltops and hillsides like a blanket.

It should be noted also that the eastward slope, which prevails in Saint Charles county from its western boundary nearly to the great rivers, shows a deep yellowish clay, which differs from the gray, loamy clay, though the exact relation of the two I have not very clearly determined. The yellow, I think, is a preglacial residuary clay of Carboniferous origin.

## Terraces, Ancient Channels and Rapids.

It is found convenient to treat these together. While we have already stated that the Pleistocene area was mainly a plain, we wish now to make an important modification of that statement. There are quite extensive areas occupied by high terraces, which are mostly formed by deposition. The principal one rises from 125 to 175 feet above the present Missouri. Others much less conspicuous are found along the Grand river and other tributaries to the Missouri, both north and south. A few small patches of a similar formation occur along the Mississippi at lower altitudes. This principal terrace generally consists of from 30 to 50 feet of buff loess, with two or three thick strata of reddish clay underneath. Below, this clay it is often interstratified with chert, pebbles and northern drift, sometimes intermixed so as to closely resemble till. In other cases, the sand and gravel may form the lower half of the terrace, 25 to 50 feet in thickness. This terrace sometimes shows rock very high in its mass, while in other localities the stratified terrace deposits extend down to the level of the present stream or even below.

This terrace is finely shown at Kansas City, both upon the north side—the river front, and also in the southern part of the city, in a valley connecting the Kansas river with the Big Blue. Many excavations show well its general structure, indicating the local derivation of much of its material. It is developed along the Big Blue near its mouth and is quite broad at Sibley. On the north bank of the Missouri it is finely shown near Camden, south of Richmond, at Brunswick, about Glasgow and extensively in the southern part of Howard county. Upon the south side of the river a small patch of it, as of an old bend, is found southwest of Lexington and again at Waverly, where an old channel leaves the present trough of the Missouri. This channel leads southeast along the present course of Salt creek to the La Mine, its southern bank passing Salt Springs and Marshall. Near the mouth of the La Mine it connects with the present channel of the Missouri; then extends still farther southeast to Billingsville, and thence east to the Missouri along the course of the Little Saline, which marks its southern bank. This channel is filled to a height corresponding to the terrace we are considering, namely, 100 to 150 feet above the present level of the stream. It shows an abundance of sand in its lower portion. In fact, its course has been traced by the occurrence of sand in deep wells along this line.

Little, if any, trace of this high terrace is found in the deep and comparatively narrow gorge reaching from near Jamestown, in northern Moniteau county, to the west line of Saint Charles county, although loess is found capping rocky ledges at a height corresponding to this terrace at Jefferson City and at Chamois.

A terrace corresponding to the one under consideration is found at Washington and Labadie, in Franklin county, and probably at other points on the southern bank of the Missouri, but is most prominently developed in the vicinity of Saint Charles, where the base is composed of limestone rising 25 feet above the river. Upon this limestone, scattered northern bowlders are found with some pebbly clay. The upper part of the terrace, as is well shown at Saint Charles, is composed of typical loess with red clay and a thin strata of red sand in its lower portion. At this point this terrace may be considered as belonging to the Mississippi, and a somewhat similar development of it may be found near Winfield and Old Monroe, while at Louisiana and near the mouth of Salt river and near Hannibal are small areas exhibiting a much more bowldery character, especially at the last point mentioned, where deep deposits of coarse gravel appear. What is believed to be the same terrace is extensively developed around Florissant and in the eastern portion of Saint Louis, extending more or less distinctly as far as the mouth of the Meramec. This terrace everywhere bears northern bowlders, sparsely scattered.

Along the course of the Missouri, in Saint Charles county below Dutzow, there is also a much eroded terrace consisting of a thick formation of loess resting upon a rocky base. This rises to the height of about 200 feet above the present stream, is well shown at Dutzow, Augusta, and less distinctly between the lower course of the Dardenne and the Missouri. It seems to correspond in structure to the loess formation at Alton. No northern drift is found upon it in the valley of the Missouri. This also covers the peninsula between the Missouri and the Mississippi in Saint Louis county as far south as Creve Cœur. Traces of loess at a similar level are found at Cape Girardeau, and surrounding the lower portion of the ancient rocky island at Grand Tower loess accumulation is built up in terrace form to the height of 125 to 130 feet. This bears evidence of being recently formed. It contains closed basins which have not yet been opened by erosion.

A small bowlder of greenstone was found at the height of about 80 feet above the Mississippi at this point. This may be considered equivalent to the lower terrace, so well developed higher up.

We should here speak of the withdrawal of the Missouri from certain channels. The valley passing through the southern part of Kansas City may be considered an old channel of the Kansas river connecting with the Big Blue. The Kansas river vacated this channel and emptied directly into the Missouri by its present course through what may have been before a mutual flood-relief channel between these two streams. This took place about the time of the formation of the high terrace already described. The change of the Missouri from the old channel leading from Waverly southeast through Saline county may have been caused in a similar way and about the same time by the Missouri preferring a similar flood-relief channel between it and the Grand river. More recently a similar change has taken place between the Little Blue and the Missouri, east of Independence. The Little Blue runs now northwest to the Missouri from a point a little east of Independence; but from the same point a broad valley, largely occupied by ponds and marshes, extends eastward to the Missouri near Napoleon. This valley is but little elevated above the present flood plain of the Missouri.

The only case of ancient rapids which has been distinctly observed is that at Weston, a little north of Leavenworth. At that point there is found on the Missouri side of the river a remarkable stratum of cobblestones and gravel 16 to 18 feet in thickness. Its base is about 140 feet above the present stream. It reaches for a mile or more in the direction of the river. It is composed mainly of limestone bowlders similar to the strata which Professor Broadhead has designated as numbers 150 to 152 of his Upper Coal Measure section.* About three and a half miles north of

* Missouri Geol. Report, part II, 1872, p. 92.

Weston he reports these strata to be 230 feet above the Missouri or 1,030 feet above the sea. It seems a pretty clear case of an ancient rapid made when the Missouri river was cutting down from the level of stratum "150." Scattered through the cobble layer are occasional bowlders of granite, red quartzite and greenstone, while the same are more abundant on the upper surface. The loess at Weston rests directly upon the cobblestone layer and rises 40 to 50 feet above it, while not far away, as near Iatan, the loess, according to Broadhead's report, rises to 335 feet above the Missouri.

This same ridge, about 12 miles northeast of Weston at Camden Point, on the Platte river, exhibits probably the same stratum at an altitude of 1,000 feet above the level of the sea. It is not unlikely that a similar deposit may be found in that vicinity. No bowldery stratum occurs on the Kansas side of the Missouri.

## Relation of present Topography to the Pleistocene Formations.

Several facts under this head have already been mentioned. These need not be repeated, and only a few of the more important need be added. The whole Pleistocene region presents in portions, more remote from streams or in localities protected from wash or erosion, patches of a very level and even surface, which we may call *flats*. This feature seems to be characteristic of the recently formed Pleistocene areas as distinct from the older formations in their vicinity. The feature appears to abound about Lathrop and Cameron and farther northwest, about Maryville, but it is much more extensive in the eastern portion of the state. It is well shown between Macon and Palmyra and between Moberly and Bowling Green; also along the Wabash line between Higby and Warrenton. Even along lines which descend from this plain the edge is quite distinctly marked. It appears also well developed on the margin of the Pleistocene at a number of points, marking quite distinctly the outline of these formations as contrasted with the high and less even surface of the older deposits. This is seen along the east side of a ridge running many miles southwest of Lexington; also near Hughesville, north of Sedalia, and near Prairie Home, in the eastern part of Cooper county. This relation appears still more distinctly near Edgewood and McCunes, in Pike county. Similar areas also appear in Warren and Montgomery counties. We have spoken of this region as a plain and have referred to its great erosion and formation of extensive terraces occupying wide areas within it. A further qualification must now be added to the general statement by calling attention to a certain deformation. Its surface rises 50 to 75 feet as it approaches the margin in eastern Boone county, and also in the vicinity of Bowling Green, Pike

county. There is also a degradation or lowering of the plain near the margin in the axes of the valleys near Salt river, Cuivre river and the Big Muddy. For example, although the general elevation of the plain on either side is about 850 feet near Troy, in the valley of the Cuivre, the drift overlaid by loamy clay rises to an altitude of less than 750 feet, and more distinctly disturbed masses may be found similarly related even down to the level of the stream.

Another feature which has a very important bearing upon our problems is the low altitude of the divide between the Missouri and Meramec rivers at Grays summit. This is traversed by a valley or col at an altitude of only 665 feet above the level of the sea. This valley, by its relief and its loose material, suggests a former channel, possibly occupied for only a short time. I found no distinctly alluvial deposits. It is bounded on the east by a rather abrupt escarpment rising over 200 feet higher. This tableland is composed of the lower formations of the Silurian rocks, the same which formed the higher knobs bounding the margin of the drift area where it lies north of the Missouri and west of the Mississippi. This col rises only a little higher than the loess-topped terrace at Augusta and Alton, and is 200 feet lower than the edge of the drift, which is only about fifteen miles distant, to the northwest.

Closely related to this fact is another, similarly surprising and significant, namely: While the Pleistocene deposits in eastern Missouri are 750 to 850 feet above the sea, similar deposits in Illinois, a few miles east, lie at an altitude of only 500 to 600 feet. In other words, one descends 250 feet in going about 50 miles. The formations and topography are alike.

## Hypotheses as to the Origin of the Pleistocene Formations.

There are but three suppositions which we conceive can be reasonably made concerning the origin of the Pleistocene formations of the region under consideration. The first ascribes them mainly to subglacial origin, the second to lacustrine conditions assisted by floating ice, and the third attributes them to flooded streams, also assisted by much floating ice.

### *DISCUSSION OF THE SUBGLACIAL HYPOTHESIS.*

*The Hypothesis stated.*—The most probable conception of the subglacial origin is about as follows: At the time of the maximum extent of the great ice-sheet it covered all areas in which are found either striated ledges or accumulations of unstratified bowldery clay. This is probably in harmony with the view generally accepted by glacialists. According to this, the land ice must have extended, at least for a short time, nearly to the boundary of the bowldery drift, or, in other words, to the vicinity

of Kansas City and the Missouri river, from that point nearly to Jefferson City, and down the Cuivre valley as far as Troy and along the Mississippi, perhaps crossing it as far south as Hannibal. This, as I understand it, has been the conception entertained by previous writers upon the Quaternary deposits of Missouri. From the light brought out by the study, the principal conclusions of which have been already given, several difficult questions arise.

*Objections to the Hypothesis.*—In considering this hypothesis one of the most serious difficulties is the disagreement of the foregoing supposition with the great difference in altitude of the drift in Missouri and that in Illinois, not fifty miles away, together with the absence of drift over Saint Louis county and down the valley of the Meramec. Since we find no gravel or other evidences of rapid streams descending from the edge of the drift down to the present river, we would naturally suppose that the waters of that mighty flood flowed gently near the altitude of the Missouri drift or, in other words, at an altitude of about 800 to 900 feet above the sea in the vicinity of the col connecting the valley of the Missouri with that of the Meramec; but the altitude of that col is less than 700 feet, and no traces of northern drift transported by water are found either upon it or down the valley of the latter stream. Moreover, no traces of northern erratics are found over the area north of this valley, as we should naturally expect if this stream ever flowed at that altitude, nor in the valley of the former stream more than 150 feet above its present level. If we suppose that this region was once sprinkled with northern erratics, it seems impossible that they should have been entirely removed by erosion. If, on the other hand, we suppose that the waters draining from the land-ice flowed in the Missouri at too low a level to escape over Grays summit into the Meramec, or to cover the high land between Saint Charles and Saint Louis, then how can we avoid the conclusion that torrential streams must have plunged violently down the short steeps from the level of the ice to that of the Missouri 200 or 300 feet below; and, if so, why should we not find numerous bowlders and fragments of torrential deposits of sand and gravel, hid away in some nooks of the old ravines? The whole margin of the supposed land-ice in Missouri must have presented phenomena of such character more or less. How impossible that all should have been swept away!

Moreover, if some solution of this difficulty could be found, so far as it concerns the bowldery drift, how could we conceive the deposition of the higher loess and gray loamy clay to have occurred with this yawning gorge all around?*

*Surely Darwin's suggestion, recently reiterated by Geikie, that valleys became choked with snow or ice, can scarcely be conceived adequate to explain this case. (Fragments of Earth-Lore, page 180; *teste,* Am. Jour. Sci., vol. 47, p. 150.)

Another difficulty is the remote distribution of the ice. We have already alluded to the great distance at which the drift is found in northern Missouri from the original center of dispersion. This was at least as far away as the northern boundary of Minnesota. Considering the movement of the ice at later stages, it must have advanced either down the valleys of the Red, James and Missouri rivers or over eastern Minnesota across the valley of the Des Moines and the high land in southern Iowa. If we suppose the glacier moved by the former route, this is certainly its greatest advance toward the south. If by the latter, we can scarcely conceive how ice should have flowed in this direction rather than into eastern Iowa and into the region which is known to be driftless.

If these two streams were confluent, as is commonly assumed, we may state the difficulty as follows: It matters little what the original starting-point of the glacier was. From the analogy of the Greenland ice-sheet, in order to extend the ice to the vicinity of Glasgow, central Missouri, the ice-sheet may have risen to an altitude of 8,000 or 9,000 feet at the north line of Iowa. The distance of the margin of the drift in eastern Nebraska from the western margin of the Wisconsin driftless area is barely 300 miles. With such an altitude of ice, why should the ice have extended southward into central Missouri full 300 miles, but scarcely half that distance eastward, else it would have encroached upon the Wisconsin driftless area? The great altitude of the western margin in Nebraska may have prevented its flow in that direction, but the present altitude of the driftless area is no greater than the high land in southern Iowa. If, as is thought by many, there was a northern depression during this stage of the ice this difficulty would have been greater. Should it be suggested that Greenland is a colder region than this was during the Ice age, and that therefore the ice need not be assumed to have been as thick, again the difficulty is only aggravated.

### *THE LACUSTRINE THEORY.*

*The Theory stated.*—Probably the best presentation of this hypothesis would be about as follows: Such was the altitude of the region under consideration that all portions now known to be strewn with northern erratics at a high level were simultaneously or successively brought beneath the waters of a great glacial lake or system of lakes, and that the loess was probably deposited in a later and greater extension of the same which probably attended the melting of the larger portion of the ice-sheet in the Missouri valley. The ice-sheet may have entered the state from the north to an indefinite distance, but the larger portion of the area was covered with subaqueous formations. Into this lake, or series of

lakes, the waters from the west and north drained. A ridge possibly* separated it from the Gasconade and the present lower Missouri, which we will suppose were then one stream flowing north to the Illinois river near Alton. The conception that a body of water depositing the loess over Missouri was continuous with the gulf of Mexico or even with a similar body to itself in southern Illinois seems to be positively forbidden by the marked differences in altitude of loamy deposits in the different areas, as has been already stated. The lake drained probably northward, perhaps into the Des Moines, which may have found its way across in an easterly direction to the Illinois river. The high land, which seems to be a continuation of this ridge in Pike county, Missouri, extends between the Mississippi and Illinois as far north as Adams county, Illinois, if not farther, and in Calhoun and Pike counties. It is reported by Professor Salisbury to be driftless.† In this lake the bowldery drift may have been deposited by the transportation of floating bergs and river ice derived from the many active glaciers farther north. As the outlet was dammed by the Illinois lobe of ice or by northward depression of the region, or by both, it became filled with loess from the glaciers which may have ceased to flow and therefore contributed little coarse material. We may also suppose that some of the loess was derived from the abundant Tertiary deposits of silt on the western plains. The upper Mississippi, before this flowing through the buried channel, reported by Mr Leverett as extending from the mouth of the Wapsipinnicon to the Illinois at Hennepin, was also dammed and emptied its waters for a time into this same lake. About this time we may suppose there was an overflow down the present course of the Mississippi above the mouth of the Illinois, which before may have been that of a smaller stream. The ice having greatly diminished and a northward elevation having begun, and the lake bed having become filled, the western streams naturally found their way along its southern border and so over the ridge bounding it on the southeast into the Gasconade. Being still swollen by waters from northern glaciers, they rapidly cut down the Missouri to its present slope.

*The evidence that this ridge was complete at that time is considerably short of demonstration. Along the line of the Wabash railroad which runs on the summit of the divide between the Cuivre and Dardenne rivers, there is quite a regular slope from Warrenton, 853 feet above tide, to Gilmore, where at an altitude of 600 feet above tide a thin sprinkling of northern crystalline pebbles are found under 10 or 12 feet of gray loamy clay as elsewhere. How this could have been formed is as puzzling a question as any presented by these problematic formations. The slope to this point from Warrenton averages 16 feet to the mile, and from Tuque 25 feet. Either the rim of the plain was incomplete here from the beginning of the Pleistocene, or in some way, not easily conceived, it was broken by erosion so early that the drift and loess both overflowed, possibly in a semi-fluid condition, or there may have been a recent tilting of this immediate region to the east.

†Proc. Am. Assoc. Adv. Sci., Washington meeting, 1891, p. 251.

*Objections to the Theory.*—In considering this theory and the evidence bearing upon it, several embarrassing questions are met. Where are the ancient beaches? If this sketch is anywhere near the truth, we may well ask where are the beach lines which should have been formed. From the analogy of lake Agassiz we should expect to find gravel beaches, and long spits and loops built out of the chert nodules occurring so abundantly along the slopes of the Burlington limestone on the south and east. On the contrary, we find no traces whatever of beach lines, nor do the fragments of chert show traces of wave action. They usually have sharp edges and prominent angles.

Why should there be no more traces of stratification? Although we may imagine that in some way beaches had been entirely removed, or that few were formed, we should still expect more cases of stratification. The average section of the deposits need not be repeated; its uniformity is surprising; and while this may not disagree with the lacustrine hypothesis, in the center of the area where the water may have been deep we should still expect to see extensive areas of unstratified sand and clay near the margins; but they have not been found.

How can this theory be reconciled with the deep troughs of the Missouri and Mississippi? We have already suggested in the statement of our theory a way by which we may ease this difficulty until we take it up in connection with the next head.

### *THE FLUVIATILE HYPOTHESIS.*

*The Hypothesis stated.*—This hypothesis may perhaps be rendered most probable by stating it somewhat as follows: Whether streams were flowing at the opening of the Pleistocene epoch at higher relative levels than now or not, we presume that a northeast extension of the Ozark uplift, between the Osage and Gasconade rivers, was intact, and that both flowed northeast into the Illinois river. The Kansas, possibly receiving the waters of the present Missouri above that point, may have flowed across past Moberly or Macon to meet the Osage. All streams were probably sluggish, except in the western part of the state. The rapids at Weston may have been forming at this stage, as also deposits of gravel up the Kansas river. As the ice-sheet advanced, probably entering the northern part of the state, these rivers were swollen to great volume, and at numerous points icebergs from the glacier's front fell into them. There was probably a northward depression of the region which made them still more lacustrine in their character, but did not entirely stop their currents. They deposited the abundant débris which was borne by them very largely in the northern portion of Missouri. In so doing they shifted back and forth until the whole region was covered with bowldery clay. In this work they were probably assisted by the Des

Moines and Mississippi, after their lower courses had been dammed by the Illinois glacier either directly or by the deposition of its sediments. Perhaps even before the plain was raised to its present level an overflow may have begun down some previous channel corresponding to the Mississippi between Quincy and the mouth of the Illinois. This outlet was rapidly excavated by the latter streams, probably accelerated by the northward elevation of the region. This same elevation threw the western streams to the southern side of the plain and over the divide into the valley of the Gasconade. These changes probably took place subsequent to the deposition of the high-level loess and gray loamy clay, and before the glaciers north had vacated the principal moraine.

While this was going on the ravines were cutting back from the lower Gasconade and Mississippi valleys through the dividing ridge on the east. This process was naturally assisted by the seepage of water from the higher level, the easy erosion of the lower Silurian shales, the porosity of the Silurian sandstone, and the easy solution and cave-forming habit of the Saint Louis limestone. Today this cutting back of ravines has but recently reached the edge of the plain near Bowling Green and Edgewood in Pike county, but we may suppose that in the axes of the Cuivre and Salt rivers, drainage and erosion may have begun very early though not before the loess had been mainly deposited.

*Objections to the Hypothesis.*—Several difficulties also present themselves in the consideration of this hypothesis. Why should there not be more traces of stratification? We are accustomed to conceive of all depositions formed by moving water as necessarily stratified. If there are no exceptions to this rule we should expect, according to this hypothesis, more or less stratification both in the bowldery and the loamy clay. We have learned in the case of loess and silt that stratification is not very manifest where all particles are very minute or where flocculation comes in to modify. May not further observation and study reveal the principle that if coarse and very fine material are both distributed at the same time, at least with the aid of ice they may be deposited together without marked signs of stratification? Cases have been found in the terraces of streams where unstratified pebbly till occurs in circumstances where it cannot be clearly traced either to subglacial or lacustrine action. Even without the aid of floating ice deposits of gravel are made upon soft clay by rapidly flowing streams. Treacherous bars of this sort are not very infrequent in clayey regions. In short, a velocity sufficient to transport pebbles is not always able to remove fine clayey material before dropping the same.

Why should there be no traces of high-level channels? According to this hypothesis we should expect traces of vacated channels in the structure of both the bowldery and the loamy clay. There should be evi-

dence of old banks and bottoms of channels. Careful search has not been made, but general examination has not yet revealed them. Some of the later channels upon the surface may have become early occupied by later streams, and so have been cut away. A glance at the map suggests that the Osage may have at one time passed along the line of the Big Muddy, in eastern Callaway county, to the south branch of the Salt river near Mexico; that the Kansas may have entered it in Callaway county, and that Grand river may have crossed in the vicinity of Moberly. Moreover, the absence of vegetation and the rapid deposition of muddy material may in part account for the absence of traces of old banks in the structure of these formations. A more careful study of such plains as that of the Hoang-Ho and Nile is advisable before we reject this hypothesis for these reasons.

How may the present location, size and depth of the troughs of the principal streams be explained? We have already, in sketching our hypothesis, suggested a reason for their locations. Probably the most formidable objection to the Lacustrine and Fluviatile theories is the excavation of the troughs of the Missouri and Mississippi since the deposition of the loess. They are 250 to 300, even in places 400 feet in depth (50 to 100 feet below the waterlevel) and from one and a half to 10 miles in width, varying inversely as the resistance of the strata traversed. Time does not allow us to discuss the matter exhaustively, and we must content ourselves with a few of the more important considerations. In discussion we shall refer principally to the Missouri because of our greater familiarity with it.

The change of baselevel was great, probably 200 to 300 feet, when first the Missouri broke over the Gasconade divide, and the erosion was of loose formations, similar to those now covering the uplands to the north.

Soon the sill of Silurian rock was reached, but it is not of a massive sort like the Niagara limestone. It easily breaks into small blocks. If the current was strong enough to wield the blocks, it must have been rapidly torn away. This, it should be remembered, is a most important factor in corrasion. If the strength of a current is not sufficient to move the separable units composing a stratum, it acts slowly, mainly by solution; but the moment that the current is able to pick up and transport blocks of average size, the larger the blocks the more rapid the erosion. We shall see that the current in this case must have been very strong. The divide between the Osage and Gasconade was not more than 12 miles in width.

But the most important consideration is the great volume of the Missouri at that time. We may estimate the area of land-ice draining into that stream during the accumulation of the first or outer moraine as

131,800 square miles in the United States; that is, one-half of Dakota, one-third of Minnesota, and one-sixth of Iowa. Besides, there was probably as great an area in Canada to be added, because the upper Saskatchewan at that time doubtless drained into the Missouri.

The ablation of certain Alpine glaciers as estimated by Desor is 10 feet a year. Forbes estimated it as over 20 feet, and as high as 2½ inches per day has been observed. It seems not unreasonable to count most of this area in the zone of ablation, and averaging 10 feet for the United States area alone, or 5 feet, to be very liberal, for that of the United States and British America. Supposing the latter to equal the former, we would then have 250 cubic miles of water furnished per year, or ten times the amount now discharged by the Missouri. In this we have not taken account of the water derived from the rest of the basin, which, if not less than now, and counting in the extension then existing into Canada as equal to the part occupied by the ice, we may put down, at a moderate calculation, that the river discharged eleven times as much water as at present, with the probability of its discharging, at least for certain years, twenty times as much. What corrasion this flood would accomplish we scarcely have the means of calculating, but can conceive that it would be fully adequate to the work. The ice-sheet would have discharged water into the Missouri river until it receded to the fourth moraine; then its waters would mostly have reached the Mississippi through the Minnesota and rapidly completed the work which that stream had previously well advanced. The prominent drift terraces and filled channels, capped with loess, may confidently be referred to the recession of the ice from the principal moraine.

## Conclusions.

In conclusion it may be noted briefly that the most serious objections to the glacial hypothesis for this region are: first, the great difference in elevation between the drift of Missouri and Illinois, with the absence of northern erratics in the lower Missouri and Meramec and along the Mississippi at higher altitudes, and last, but not least, the apparent impossibility of the land-ice reaching central Missouri without overflowing the Wisconsin driftless area. The most weighty difficulties with the lacustrine and fluviatile theories are the nature of the deposits and the great depth and width of the troughs of the Missouri and Mississippi. Possibly more careful research in the nature of deposition and erosion may remove them. It seems not improbable that a combination of the last two may approach the truth more nearly than either one alone.

Vermillion, S. D., *December* 22, 1893.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 5, PP. 549-665, PLS. 20, 21 APRIL 30, 1894

# PROCEEDINGS OF THE SIXTH ANNUAL MEETING, HELD AT BOSTON, DECEMBER 27, 28 AND 29, 1893

HERMAN LEROY FAIRCHILD, *Secretary*

## CONTENTS

## Session of Wednesday, December 27

The Society convened in the hall of the Boston Society of Natural History, and was called to order at 10.15 a m by the President, Sir J. William Dawson. The President introduced Professor William H. Niles, the President of the Boston Society of Natural History, who, in a cordial address of welcome, said that the old Society, of sixty-four years' standing, welcomed to the city and to its building the new Society of six years' age, representative of the entire continent of North America. He reviewed the progress which had been made in scientific knowledge and in its public appreciation since the founding of the organization in whose building this meeting was held, and contrasted the time when Sir Charles Lyell was in Boston and public feeling was so strongly against the conclusions of geological study, and the present day, when the results of such investigation are universally acknowledged to be for the highest interests of humanity. President Dawson responded happily. As chairman of the Local Committee of Entertainment, composed of the Fellows residing in and near Boston, Professor Niles made announcements concerning entertainment during the meeting.

The Secretary announced that the Council would present its report Friday morning.

The Treasurer, Dr I. C. White, presented his annual report as follows:

### *REPORT OF THE TREASURER*

The invested funds of the Society are as follows:

| | | |
|---|---|---|
| On account of Fellowship Fund: | | |
| April 1, 1891. One 7 per cent Tioga township, Kansas, bond, with accrued interest (cost $1,140.26)....... | $1,000 00 | |
| January 29, 1892. Eight 5 per cent Cosmos Club bonds at par | 800 00 | |
| | | $1,800 00 |
| On account of Publication Fund: | | |
| February 26, 1892. One 5 per cent Cosmos Club bond, with accrued interest (cost $100.35)......... | $100 00 | |
| February 3, 1893. Seven 5 per cent Cosmos Club bonds at par | 700 00 | |
| | | $800 00 |
| Total amount of investments.............................. | | $2,600 00 |

*Balance-sheet.*

| RECEIPTS. | | |
|---|---|---|
| Balance in treasury November 30, 1892 | | $601 15 |
| Fellowship fees for 1891 (1) | $10 00 | |
| " " 1892 (17) | 170 00 | |
| " " 1893 (165) | 1,650 00 | |
| " " 1894 (1) | 10 00 | |
| | | 1,840 00 |
| Initiation fees (8) | | 80 00 |
| Interest on investments: | | |
| On Kansas Tioga township bonds | $70 00 | |
| On Cosmos Club bonds | 62 50 | |
| On bank time certificates | 17 65 | |
| | | 150 15 |
| Sales of Bulletin: | | |
| Cash from the Secretary | $380 30 | |
| Deposited by the Secretary in Security Trust Company, Rochester, N. Y., to order of Treasurer | 217 75 | |
| | | 598 05 |
| Assessments on cost of publications | | 2 00 |
| Bank time certificates cashed | | 588 55 |
| Total | | $3,859 90 |

| EXPENDITURES. | | |
|---|---|---|
| Expenses of administration. | | |
| Secretary's office: | | |
| H. L. Fairchild | $453 20 | |
| Rochester Printing Company | 148 30 | |
| E. R. Andrews | 9 50 | |
| Alling & Cory | 17 50 | |
| | | $628 50 |
| Photograph Committee: | | |
| J. S. Diller | | 11 67 |
| Publication of Bulletin. | | |
| Editor's office: | | |
| J. Stanley-Brown | $17 00 | |
| W J McGee | 17 20 | |
| Printing: | | |
| Judd & Detweiler | 1,674 19 | |
| Engraving: | | |
| Moss Engraving Company | 159 50 | |
| Standard Engraving Company | 9 00 | |
| Photo Engraving Company | 6 75 | |
| Error in assessment: | | |
| Refunded to A. H. Cole | 3 00 | |
| | | 1,886 64 |
| Investment account. | | |
| Bond purchases: | | |
| 7 Cosmos Club bonds | | 700 00 |
| Cash, balance in treasury November 30, 1893 | | 633 09 |
| Total | | $3,859 90 |

As the Auditing Committee the Society elected I. C. Russell and J. P. Iddings.

*ELECTION OF OFFICERS.*

The result of the balloting for officers for 1894, as canvassed by the Council, was declared by the Secretary.

No election was secured by the transmitted ballots for the offices of President and Vice-Presidents, as no candidate had a majority of all the votes cast.

For the remaining offices election had been made as follows:

*Secretary:*

H. L. Fairchild, Rochester, N. Y.

*Treasurer:*

I. C. White, Morgantown, W. Va.

*Editor:*

J. Stanley-Brown, Washington, D. C.

*Councillors* (term expires 1896):

F. D. Adams, Montreal, Canada.
I. C. Russell, Ann Arbor, Mich.

Under chapter iv, section 4, of the By-Laws, election of President and Vice-Presidents was held in open meeting separately, by ballot. The President named as tellers to supervise the balloting J. Stanley-Brown and C. W. Hayes. The result was as follows:

*President:*

T. C. Chamberlin, Chicago, Ill.

*First Vice-President:*

N. S. Shaler, Cambridge, Mass.

*Second Vice-President:*

G. H. Williams, Baltimore, Md.

### *ELECTION OF FELLOWS*

The result of the balloting for Fellows, as canvassed by the Council, was declared as follows:

*Fellows Elected:*

ALBERT PERRY BRIGHAM, A. B., A. M., Hamilton, New York. Professor of Geology and Natural History, Colgate University.

WILLIAM STUKELY GRESLEY, Erie, Pennsylvania, Mining Engineer.

HEINRICH RIES, Ph. B., Fellow in Mineralogy, Columbia College, New York city.

JAMES PERRIN SMITH, M. S., Ph. D., Palo Alto, California. Assistant Professor of Paleontology, Leland Stanford, Jr., University.

### *AMENDMENTS TO THE CONSTITUTION*

The proposed amendment to article iii, section 1, by omitting the closing words of the section, "and resident in North America," so that the section shall read, "1. Fellows shall be persons who are engaged in geological work or in teaching geology," received 130 votes in favor and 10 votes against.

The proposed amendment to article iv, section 8, by inserting after the word "Editor" the words "and Treasurer," so that the paragraph shall read, "The Secretary, Editor and Treasurer shall be eligible to reëlection without limitation," received 134 affirmative and 3 negative votes.

The proposed amendments were declared lost, failing to receive a three-fourths affirmative vote of the total membership. The Secretary announced that the Council would again submit the amendments to the Society.

### *AMENDMENTS TO THE BY-LAWS*

The proposed changes in the By-Laws, as recommended by the Council at the Madison meeting and announced in the Secretary's circular of September 13, 1893, were declared in order under unfinished business, and the amendments were unanimously voted as follows:

Chapter I, section 2, changed by omitting all between the words "shall be" and the word "covered," so that the paragraph now reads: 2. "The sum paid in commutation of dues shall be covered into the Publication Fund."

Chapter IV, by omitting all of the first two sections and substituting, reads as follows:

## CHAPTER IV

### OF ELECTION OF OFFICERS

1. The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket.

2. The list shall be mailed to the Fellows for their information at least 40 days before the Annual Meeting. Any five Fellows may forward to the Secretary other

nominations for any or all offices. All such nominations reaching the Secretary at least 20 days before the Annual Meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows at least 15 days before the Annual Meeting.

3. The Fellows will send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the winter meeting of the Council the Secretary will bring the returns of ballots before the Council for canvass, and during the winter meeting of the Society the Council shall declare the result.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such winter meeting proceed to make an election for such office from the two candidates having the highest number of votes.

Chapter VIII changed to read as follows:

## CHAPTER VIII

### OF ORDER OF BUSINESS

1. The Order of Business at Winter Meetings shall be as follows:

(1) Call to order by the presiding officer.
(2) Introductory ceremonies.
(3) Report of the Council (including reports of the officers).
(4) Appointment of the Auditing Committee.
(5) Declaration of the vote for officers and election by the meeting in case of failure to elect by the Society through transmitted ballots.
(6) Declaration of the vote for Fellows.
(7) Deferred business.
(8) New business.
(9) Announcements.
(10) Necrology.
(11) Reading of scientific papers.

2. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.

3. At the Summer Meeting the items of business under numbers (3), (4), (5), (10) shall be omitted.

4. At any Special Meeting the Order of Business shall be numbers (1), (2), (3), (9), followed by the special business for which the meeting was called.

The report of the Committee on Photographs was presented by Mr J. S. Diller.

### *FOURTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS*

Sixty-one views have been added during the year to the collection, which now numbers 802. The donors are C. H. James, Henry G. Hanks, H. A. Riddle and W. H. Hobbs, as noted in the following register.

The collection was exhibited at the Boston meeting of the Society, and is always accessible to members at the United States Geological Survey, Washington, D. C., where it is in charge of J. S. Diller, the Secretary of the committee.

Good mounted photographs of geological subjects, properly labeled, are solicited as heretofore, and contributions may be sent to Professor J. F. Kemp, Columbia College, New York city; Professor W. M. Davis, Harvard College, Cambridge, Mass., or to Mr J. S. Diller, United States Geological Survey, Washington, D. C.

There is demand for such photographs as furnish especially good illustrations in teaching, and it is hoped that the members will call the attention of the Secretary to any which the committee may obtain by solicitation.

### REGISTER OF PHOTOGRAPHS RECEIVED IN 1893

*Photographed and presented by C. H. James, 624 Arch Street, Philadelphia, Pennsylvania*

Twelve Stereoscopic views of the Luray Caverns of Virginia. Price, 25 cents each.

741 (15). Side view in ball-room.
742 (19). Collin's grotto.
743 (25). Entrance to ball-room.
744 (27). Double column.
745 (29). Giant's hall.
746 (33). Lost blanket.
747 (35). Titania's veil from Hollow column.
748 (37). Empress column.
749 (41). Saracen's tent.
750 (43). Fallen column.
751 (47). Organ room.
752 (71). Skeleton gorge.

*Presented by Henry G. Hanks, San Francisco, California*

Photographed by C. E. Watkins. Size, 6½ x 8½ inches

753. Hanksite; crystallized variety.
754. Hanksite; amorphous and imperfectly crystallized variety.

*Presented by H. A. Riddle, Chambersburg, Pennsylvania*

755. Photogravure of a Relief Map of the Cumberland valley of Pennsylvania

By applying to Mr Riddle members of the Society may obtain this photogravure gratis. Size, 11¾ x 3¼ inches.

*Photographed and presented by W. H. Hobbs, Madison, Wisconsin*

These views illustrate two papers which are published in the Journal of Geology, vol. i, p. 717, "On the Geological Structure of the Mount Washington Mass of the Taconic Range," and p. 780, "The Geological Structure of the Housatonic Valley east of Mount Washington." They may be purchased from the donor at the following rates: Size, 4 x 5 inches; unmounted, 7 cents; mounted, 10 cents. Size, 8 x 10 inches; unmounted, 12 cents; mounted, 18 cents.

756. Mount Washington from the north; looking up Guilder hollow. To the left is "Jug End." In the distance is the "Dome" or mount Everett, between is mount Darby. Size, 8 x 10 inches.

757. Panorama from summit of mount Everett; looking northeast. Size, 8 x 10 inches.
758. Panorama from summit of mount Everett; looking southeast. Size, 8 x 10 inches.
759. Panorama; looking west down the Bashbish gorge of mount Washington. Size, 8 x 10 inches.
760. Mount Washington; the Dome of the Taconics; looking northwest. Size, 4 x 5 inches.
761. Mount Washington; from the southeast. Size, 4 x 5 inches.
762. Mount Washington and Twin lakes; from the southeast. Size, 4 x 5 inches.
763. Mount Washington and Turnip rock; from the southeast. Size, 4 x 5 inches.
764. Looking up Guilder hollow, mount Washington. Size, 4 x 5 inches.
765. Looking up Guilder hollow, mount Washington; Jug End at left; mount Everett in the distance. Size, 4 x 5 inches.
766. East flank of mount Washington; seen from Turnip rock. Size, 4 x 5 inches.
767. East flank of mount Washington; near view. Size, 4 x 5 inches.
768. Valley of Sky Farm brook; looking north from Sky Farm. Size, 4 x 5 inches.
769. Northern summit plain of mount Washington; looking southeast from Sky Farm. Size, 4 x 5 inches.
770. Lion's head from the east; showing indications of northerly dip. Size, 4 x 5 inches.
771. View northwest; from west slope of Barack M' Teth. Size, 4 x 5 inches.
772. Peculiar weathering of Egremont limestone on east slope of mount Washington. Size, 4 x 5 inches.
773. Corrugations of Riga schist forming surface one mile south of Washinee lake. Size, 4 x 5 inches.
774. Valley of Sky Farm brook; looking north from one-half mile north of Sky Farm. Size, 4 x 5 inches.
775. In the region of mount Washington. Size, 4 x 5 inches.
776. Egremont limestone with Riga schist two miles west of Dutcher's bridge over Housatonic river. Size, 4 x 5 inches.
777. North end of hill east of Lee pond, mount Washington. Size, 4 x 5 inches.
778. Horse hill; from Barnum street, Sheffield, Massachusetts. Size, 8 x 10 inches.
779. Horse hill; from ridge south of Barnum street; Warner mount to the right in the distance. Size, 8 x 10 inches.
780. The core of Canaan dolomite in a fold of Riga schist. (Journal of Geology, pl. vii, fig. 3.) Size, 8 x 10 inches.
781. Narrow ridges of Riga schist separated by belts of Egremont limestone near railroad bridge southeast of Tom's hill. This is typical "intricate structure." Size, 8 x 10 inches.
782. Corrugations of Everett schist, having a steep southerly pitch, north foot of Barack M' Teth. Size, 8 x 10 inches.
783. View southeast; from near road $\frac{3}{4}$ mile north of the village of Salisbury. In the center is the west slope of Barack M' Teth. Size, 8 x 10 inches.
784. View east from road one mile north of Salisbury. In the foreground are characteristic knobs of Riga schist. (Journal of Geology, vol. i, no. 8, pl. vii, fig. 1.) Size, 8 x 10 inches.
785. View northeast from the summit of Prospect mountain (Housatonic valley), showing in center of picture Canaan dolomite emerging from beneath Riga schist. (Wooded area.) Size, 4 x 5 inches.
786. Tom's hill from east flank of Lion's head. Size, 4 x 5 inches.
787. C. N. E. & W. railroad south of Tom's hill, showing the Riga schist pitching steeply south under Egremont limestone. Size, 4 x 5 inches.
788. Same as 787. Size, 4 x 5 inches.

789. Near view of a ruptured loop in Egremont limestone; transition from corrugations to imbricated structure; C. N. E. & W. railroad south of Tom's hill. Size, 4 x 5 inches.

790. Pine hill on C. N. E. & W. railroad south of Tom's hill; Riga schist with steep southerly pitch is seen on the left of track; Pine hill is Egremont limestone dipping conformably; in woods behind telegraph pole at right is Everett schist overlying the limestone. (Journal of Geology, vol. i, no. 8, fig. 6.) Size, 4 x 5 inches.

791. Abrupt north slope of Barack M' Teth (Everett schist) from the east. On the road and above is Egremont limestone dipping under the hill. Size, 4 x 5 inches.

792. Barack M' Teth and Turnip rock from the west. Size, 4 x 5 inches.

793. Union hill from the north. Size, 4 x 5 inches.

794. Turnip rock from the east, showing Egremont limestone dipping under Everett schist of the hill. Size, 4 x 5 inches.

795. Turnip rock from the southwest, showing basement of limestone (Egremont). Size, 4 x 5 inches.

796. Turnip rock from the southwest; Egremont limestone in the foreground. Size, 4 x 5 inches.

797. Falls of the Housatonic river at Falls Village, Connecticut. Size, 4 x 5 inches.

798. South end of anticlinal of Riga schist with mantle of limestone, where both pitch under Everett schist of Barack M' Teth. From road at north foot of Barack M' Teth. Size, 4 x 5 inches.

799. Canaan dolomite emerging beneath Riga schist 2½ miles north of Falls Village, Connecticut. Size, 4 x 5 inches.

800. Corrugated structure of garnetiferous and staurolitic Riga schist near falls, north of Falls Village, Connecticut. Size, 4 x 5 inches.

801. Miles mountain and Tom's hill from the northwest, showing serrated contour. (Journal of Geology, vol. i, no. 8, fig. 3.) Size, 8 x 10 inches.

802. Northern summit plain of mount Washington, showing the rampart of peaks which surround it. Size, 8 x 10 inches.

The report was adopted and the committee continued with an appropriation of $15 for its use during the coming year.

An invitation from the Appalachian Mountain Club to a lecture on Mount Saint Elias and the Malaspina Glacier, to be given Friday evening, by Professor I. C. Russell, was read and thanks returned by the President.

The President congratulated the Society that no losses to its Fellowship by death had occurred during the year.

Following are lists of geological writings which were not published with the biographic notices of the deceased Fellows:

### GEOLOGICAL WRITINGS OF ALEXANDER WINCHELL *

On the Geology of the Choctaw Bluff: *Proc. Am. Assoc. Adv. Sci.*, vol. vii, 1853, pp. 150–153.

The Shell Marls of Michigan: *Mich. Farmer*, September, 1855, pp. 257–259.

* Biographic notice in volume 3, p. 3. This list of Dr Winchell's geologic writings is taken from a fuller list published in The American Geologist, vol. 9, pp. 127–139 and pp. 273–276.

Notes on the Geology of Middle and Southern Alabama: *Proc. Am. Assoc. Adv. Sci.*, vol. x, 1856, pp. 82–93.

Statistics of some Artesian Wells of Alabama: *Proc. Am. Assoc. Adv. Sci.*, vol. x, 1866, pp. 94–103.

Theologico-Geology, or the Teachings of Scripture illustrated by the Conformation of the Earth's Crust. Ann Arbor: *Pamphlet*, 1857, 8vo, pp. 24.

Table of Cretaceous Rocks in Alabama: *Proc. Acad. Nat. Sci. Phila.*, vol. ix, 1857, pp. 126.

Superficial Deposits of Michigan and Alabama: *Harper's Geol. Rep. of Miss.*, 1857, pp. 316–318.

Voices from Nature; Creation the Work of One Intelligence and not the Product of Physical Forces; being the closing lecture of a course upon Geology and Natural History, delivered before the Young Men's Literary Association of Ann Arbor, Mich. Published by request of the Association, 1858, 8vo, pp. 26.

Synoptical View of the Geological Succession of Organic Types. For the use of students in the University of Michigan, and printed at their request, May, 1858. Ann Arbor, 8vo, pp. 7.

Leaves from the Book of Nature: *Mich. Jour. Educ.*, vol. ii, 1858, pp. 74–77, 97–100, 132–136, 169–173, 193–197, 225–229, 257–263, 305–310, 353–356.

Outlines of the Geology of Michigan: *Mich. Farmer*, December, 1858.

Memorial Relative to a Geological Survey: *House Doc., No. 29*, Legislature of 1859, pp. 10.

Scenes and Incidents of the Coal Period: *Mich. Jour. Educ.*, vol. vi, 1859, pp. 13–20.

On the Geological Position of the Brine Springs of Grand Rapids, Mich.: *Grand Rapids papers*, October, 1859.

On the Salt Springs of Saginaw: *Saginaw Enterprise*, February, 1860.

The Cycles of Matter, or the Permanence of the Earth and the Destiny of the Race: *Mich. Jour. Educ.*, August, 1860, pp. 273–280.

First Biennial Report of the Progress of the Geological Survey of Michigan, embracing observations on the Geology, Zoölogy and Botany of the Lower Peninsula; made to the Governor December 31, 1860, by authority: Lansing, 1861, 8vo, pp. 339.

Notice of the Rocks lying between the Carboniferous Limestones of the Lower Peninsula of Michigan and the Limestones of the Hamilton Group; with descriptions of some Cephalopods supposed to be new to Science: *Am. Jour. Sci.*, 2d series, vol. xxxiii, pp. 352–366.

Salt Manufacture of the Saginaw Valley: *Hunt's Merchants' Magazine*, September, 1862, pp. 209–223.

The Brine at Bay City: *Saginaw Courier*, July, 1862.

On the Saliferous Rocks and Salt Springs of Michigan: *Am. Jour. Sci.*, 2d series, vol. xxxiv, pp. 307–311.

Descriptions of Fossils from the Marshall and Huron Groups of Michigan: *Proc. Acad. Nat. Sci. Phila.*, vol. xiv, 1862, pp. 405–430.

On the Identification of the Catskill Red Sandstone Group with the Chemung: *Am. Jour. Sci. and Arts*, 2d series, vol. xxxv, 1863, pp. 61, 62.

Descriptions of Fossils from the Yellow Sandstones lying beneath the "Burlington Limestone" at Burlington, Iowa: *Proc. Acad. Nat. Sci. Phila.*, vol. xv., 1863, pp. 2–24.

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BY FRANK A. HILL

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## *GEOLOGICAL WRITINGS OF DAVID HONEYMAN**

BY J. G. MCGREGOR †

*Published in Transactions of the Nova Scotian Institute of Science*

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† Mr McGregor is Secretary of the Nova Scotian Institute of Science, and his kindness in preparing the list is gratefully recognized by the Society.

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Report on the Geology of the Southern Division of New Jersey: *Second Ann. Rep. of the Geol. Survey of New Jersey for 1855*, pp. 53–108.
Report on the Progress of the Geological Survey of the Southern Division of the State during the year 1856: *Third Ann. Rep. of the Geol. Survey of New Jersey for 1856*, pp. 39–68.
Final Report on the Geology of the County of Cape May: *Geol. of the County of Cape May, N. J.*, pp. 1–134.
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## *GEOLOGICAL WRITINGS OF RICHARD OWEN**

BY JOSEPH STANLEY-BROWN

Report [on Pigeon Point]: In *Report of a Geological Survey of Wisconsin, Iowa and Minnesota, and incidentally of a portion of Nebraska Territory*, by David Dale Owen: Philadelphia, 1852, 4to, pp. 397–400.

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Report on the Mines of New Mexico [joint author with E. T. Cox]: Washington, D. C., 1865, 8vo, 59 pages.

[Visit to the newly discovered Deposit of Rock Salt, near New Iberia, on the Gulf Coast, in the State of Louisiana]: Communication made before the Saint Louis Academy of Sciences September 5, 1864; published in *Trans. Saint Louis Acad. Sci.*, vol. ii, 1868, pp. 250-252; reprinted in extenso in *Am. Jour. Sci.*, 2d ser., vol. xlii, 1866, pp. 120–123.

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Contributions to physiographic and dynamical Geology, involving the Discussion of terrestrial Magnetism: *Proc. Am. Assoc. Adv. Sci.*, 20th meeting, Indianapolis, 1871, pp. 208–216; *Franklin Instit. Jour.*, 3d ser., vol. lxii, 1871, pp. 270–278.

Terrestrial Magnetism [including a discussion of recent volcanoes and earthquakes]: *Franklin Instit. Jour.*, 3d ser., vol. lxiv, 1872, pp. 126–132.

Arkansas; *Macfarlane's Geol. R. R. Guide*, 1879, p. 206; second edition, 1890, p. 406.

The Law of Land-forming on our Globe: *Proc. Am. Assoc. Adv. Sci.*, 29th meeting, Boston, 1880, pp. 437–446.

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* Biographic notice in volume 2, p. 610.

Résumé d'un Rapport sur l'Unification de la Nomenclature géologique: *Congrès Géologique International*, Compte Rendu, 2me session, Bologne, 1881, pp. 623–626.

Contribution to Seismology [Abstract]: *Proc. Am. Assoc. Adv. Sci.*, 31st meeting, Montreal, 1882, pp. 329–336.

Law of Fracture, or Fissuring, applied to inorganic and organic Matter [Abstract]: *Proc. Am. Assoc. Adv. Sci.*, 31st meeting, Montreal, 1882, pp. 337–344.

The Earth's orographic Frame-work: Its Seismology and Geology [Abstract]: *Proc. Am. Assoc. Adv. Sci.*, 32d meeting, Minneapolis, 1883, pp. 253–256.

The continental Type, or normal Orography and Geology of Continents [Abstract]: *Proc. Am. Assoc. Adv. Sci.*, 32d meeting, Minneapolis, 1883, pp. 256–260.

British Earthquakes and their seismic Relations [Abstract]: *Proc. Am. Assoc. Adv. Sci.*, 33d meeting, Philadelphia, 1884, pp. 438-443; also *Am. Meteorological Jour.*, vol. i, December, 1884, pp. 317–321.

The recent Earthquake in Greece and other Places on August 28, 1886: *Am. Meteorological Jour.*, vol. iii, September, 1886, pp. 220–222.

The Relation between geographical Forms and geological Formations: *Am. Meteorological Jour.*. vol. iv, November, 1887, pp. 309–313.

The Relation of the Pole of the Land Hemisphere to Continents, to the magnetic System, and to seismic Force [Abstract]: *Am. Meteorological Jour.*, vol. iv, October, 1887, pp. 275–280.

Derivation of the terrestrial Spheroid: *Am. Meteorological Jour.*, vol. v, November, 1888, pp. 289–293.

Additional Facts respecting the Law governing the Distribution in space of Seismism: *Am. Meteorological Jour.*, vol. v, January, 1889, pp. 419-421.

The President declared the reading of scientific papers in order. Before the reading began, the following rule of the Council relating to papers was announced:

" *Resolved*, That in view of the large number of papers offered for this " meeting, and in order to economize time, the Council rules that papers " whose authors are not present when the title is called shall go to the " end of the program, unless the Society by special vote in each case " decides otherwise."

The first paper on the printed program, following the title of the Presidential Address, was, in the absence of the author, held in place by special vote, and was read by the President:

### *GEOLOGICAL NOTES ON SOME OF THE COASTS AND ISLANDS OF BERING SEA AND VICINITY*

BY GEORGE M. DAWSON

This paper is printed as pages 117–146 of this volume.

The next paper was read, in the absence of the author, by T. W. Stanton:

# FOSSIL FLORA OF ALASKA

BY FRANK H. KNOWLTON

[*Abstract*] *

*Contents*



## Introduction

In studying a collection of leaves from Herendeen bay and interglacial wood from beneath Muir glacier, I recently had occasion to go over the literature relating to the fossil flora of Alaska. This literature is somewhat widely scattered; and as a matter of personal interest and convenience, a list of the species of fossil plants heretofore reported from Alaska was compiled. This list was used in determining the collections above mentioned; and after completing the identifications and descriptions of new species found in the collection, it was decided to present a complete compilation of the fossil flora. This is done partly with the hope that it may stimulate further investigation of the paleobotany, for the distribution of the plant-bearing beds, some of which are represented by single examples, indicates that much remains to be accomplished. This is further shown by the fact that every collection contains a good proportion of new species.

I have first prepared a historical review of works and papers relating to the fossil flora of Alaska, which incidentally shows the geographical distribution of the plant beds. This is followed by a systematic enumeration of the fossil plants, and a discussion of the geologic age of the beds as indicated by the plants.

## Historical Review

One of the first accounts of fossil plants in Alaska was given by Dr C. Grewingk† in his classical history of the northwestern coast of America. This is in the main a compilation, though the sources from which he derived his information are obscure, and I have not been able to find them. It is hardly probable that if found they would prove of much value. He reported coniferous wood from the islands of Kadiak and Unga and from the Alaskan peninsula, and dicotyledons (*Alnus*) and conifers (*Taxodium*) from Tschugatsk (Cook inlet) and Unalaschka. He also mentioned a fern from Unga which he supposed to have some resemblance to *Neuropteris acutifolia*. It is probably the same as *Osmunda doroschkiana* of Göppert, as no Carboniferous fossils are known from Unga.

* The paper is printed in full and the recently founded species referred to in this abstract are described and illustrated in Proc. U. S. National Museum, vol. xvii, 1893, pp. 207–240, pl. ix.

† Beitrag zur Kennt. d. Orographischen und Geognostischen Beschaffenheit d. Nord-West Küste Amerikas mit Anliegenden Inseln: Verhandl. d. Russ-Kais. Mineralog. Gesell. St. Petersb., 1848–1849; Saint Petersburg, 1850, pp. 41, 93, 97, 124.

A year later, Grewingk again referred * to fossil plants in Alaska, especially to the fossil trunks on Unga island, but nothing beyond this appears to have been noticed. †

In 1861 Göppert reported ‡ on a small collection of fossil plants obtained in August, 1859, by Lieutenant von Doroshin § from the islands of Kadiak and Uyak (latitude $57\frac{1}{2}°$) ‖, Atka (latitude 52°) ¶, and Kootznahoo (latitude $57\frac{1}{2}°$) **. The last of these, Kootznahoo, is in the vicinity of or is a part of Admiralty island, near Sitka. It afforded two species of dicotyledons and a single conifer. From the combined localities Göppert enumerated eleven species, a number of which were new; but he did not describe them.

In 1866 the same collection was again referred to by Göppert, †† though unfortunately, the descriptions were not even then supplied, and consequently most of the names remain *nomina nuda*.

In December, 1867, Professor Oswald Heer, of Zurich, wrote a letter relating to Alaskan plants to Professor A. E. Nordenskiöld of Stockholm, which was published in the following year. ‡‡ It was an enumeration of the plants brought back by Furuhjelm, and may be considered as an outline of Heer's larger work which appeared in 1869. The plants were arranged according to localities, and most of the new species were briefly characterized.

In many respects the most important paper on the fossil plants of Alaska is Heer's *Flora Fossilis Alaskana*, §§ which was published in 1869. It was based, as stated above, on collections brought back by Hjalmar Furuhjelm, of Helsingfors, Finland, who, as governor of the Russian-American possessions, resided for nearly ten years in Alaska. He made, it appears, a very large collection, most of which was lost on the Mexican coast by the stranding of the ship in which they were being sent home. The specimens which finally reached Europe were obtained from the island of Kuiu, ‖‖ near Sitka, and from the eastern side of Cook inlet; a part coming from English bay, now better known as Port Graham (latitude 59° 21′; longitude 151° 52′), and the rest from near a small stream known as the Nenilt-schik (latitude 60° 9′). The latter place is about 50 miles north of Port Graham. This paper enumerates fifty-six species, of which number nineteen were then new to science.

* Heidlb. Jahrb. Lit., 1851, p. 235.

† For the modern designations and orthography of Alaskan localities I am greatly indebted to Mr Marcus Baker of the United States Geological Survey.

‡ Ueber d. Tertiärfl. d. Polargegenden: Abhandl. d. Schles. Gesell. für Vaterländ-Cult., 1861, heft. II, pp. 201–204.

This paper is also published under the same title in Mélanges Physique et Chimiques tirés du Bulletin de l'Acad. Imp. des. sc. de St. Petersbourg, tome IV, 1860–'61; Saint Petersburg, 1861, pp. 695–712.

§ This name is written "Doroschkin" by Göppert, but is an obvious German rendering of the Russian Doroshin.

‖ This is probably from a bay of this name on the northwestern coast of Kadiak, but as there are several nameless islands in this bay it is possible that it may be one of them.

¶ This was written "Atha" by Göppert, but Atka is the modern spelling.

** Given as "Hudsnoi" by Göppert, which is one of the earlier of the many renderings of the word Kootznahoo.

†† Abhandl. d. Schles. Gesell. f. Vaterländ-Cult., 1865–'66; Breslau, 1867, p. 50.

‡‡ Utdrag ur ett bvef af Professor Oswald Heer rovande fossila vexter fran Nordvestra Amerika, insamlade af Bergmästaren Hj. Furuhjelm: Öfversigt af Vetensaps-Akad. Förhandl., 1868; no. 1 pp. 63–68.

§§ Kongl. Svenska Vetenskaps-Akad. Handl, vol. VIII, no. 4, 1869, pp. 1–41, pl. I–X.

‖‖ Written "Kuju" by Heer.

In 1871 Eichwald * made a reëxamination of the plants collected by Lieutenant von Doroshin that had first been studied, as above pointed out, by Göppert in 1861. Göppert, it will be remembered, did not give figures or descriptions of these plants in his paper. These were supplied by Eichwald, who also made use of Heer's *Flora Fossilis Alaskana* in working over the collection. He enumerated 9 species, 3 of which were newly named, although they had been recognized by Göppert or Heer. Eichwald also gave a list of the species reported from all parts of Alaska by Heer.

In 1882 Lesquereux published a paper entitled "Contributions to the Miocene Flora of Alaska," † which was based on material brought back by Dr William H. Dall, then of the United States Coast and Geodetic Survey. The plants, which according to Lesquereux were finely preserved, came from Coal Harbor, Unga island; Kachemak bay, ‡ Cook inlet; and Chignik bay, Alaskan peninsula (latitude 56½°). It enumerated twenty-one species of which seven were regarded as new to science. This paper was republished, without the illustrations, in Lesquereux's "Cretaceous and Tertiary Floras," as one of the reports of the Hayden survey. §

Also in 1882, Dr J. S. Newberry described new species of fossil plants from Alaska in his paper entitled "Brief Descriptions of Fossil Plants, chiefly Tertiary, from western North America." ‖ They were collected by Captain Howard, United States Navy, in Cook inlet and Admiralty inlet, ¶ and by the United States Steamer *Saginaw*, in Kootznahoo archipelago (latitude 57° 35′; longitude 134° 19′), the last on February 18, 1869.

The figures illustrating the foregoing collection of plants were prepared and the plates were engraved and printed in 1871, but have not yet been formally issued. They were designed to form the illustrations of a monograph of the Hayden survey for which the text was never supplied. A posthumous work, which will embrace these plates, is in preparation by Dr Newberry's successor in Columbia College, Dr Arthur Hollick. They are quoted in the present paper as "Plates."

In 1887 Lesquereux published a paper entitled "List of recently identified Fossil Plants belonging to the United States National Museum, with descriptions of several new Species." ** This comprised a large amount of material that had been accumulating in the department of fossil plants since the founding of the Smithsonian Institution. Among them were a few species recorded as having been collected in the vicinity of Sitka by E. W. Nelson, †† and at cape Lisburn by H. D. Woolfe. The specimens from the latter place appear to have been a part of the collection that was described from the same locality in the following year, they having been accidentally separated.

* Geognostisch-Palæontologische Bemerkungen über die Halbinsel Mangischlak und die Aleutischen Inseln; Saint Petersburg, 1871, pp. 107-116, pl. IV.

† Proc. U. S. Nat. Mus., vol. v, 1882 (1883), pp. 443-449, pl. VI-X.

‡ Often called Chugachik bay, and so written by Lesquereux.

§ Vol. viii, 1883, pp. 257-263.

‖ Proc. U. S. Nat. Mus., vol. v, 1882 (1883), pp. 502-514.

¶ This is presumably an error for Admiralty island, there being no inlet bearing the name Admiralty known in Alaska.

** Proc. U. S Nat. Mus., vol. x, 1887, pp. 21-46, pl. I-IV.

†† I am informed by Mr. Nelson that he never visited Sitka and did not bring back any fossil plants from Alaska. This throws doubt on the specimens so recorded, and their locality and collector remain unknown. I have retained them, however, as recorded by Lesquereux.

In 1888, as stated above, Lesquereux published* an enumeration of plants obtained at cape Lisburn by H. D. Woolfe. This collection included ten species, of which number only one was regarded as new to science.

The last paper dealing with preglacial fossils is one by Felix† in which he described two species of silicified wood, one obtained by Dr Krause of Berlin on a basalt mountain south of Danaáka,‡ and the other from Copper island, § in the southwestern part of Bering sea.

F. H. Herrick is the only investigator, so far as I now know, who has identified any of the interglacial wood. His paper, "Microscopical Examination of Wood from the buried Forest, Muir Inlet, Alaska," was published as Supplement III to Harry Fielding Reid's paper "Studies of Muir Glacier, Alaska." ‖ Professor Herrick identified the wood submitted to him with the tide-land spruce (*Picea sitchensis*, Carr.) now living about the glacier, "provided that microscopical examination of the wood alone could be relied upon for the determination of species of coniferous trees."

A number of pieces of wood from the buried forest of Muir glacier, obtained in 1892 by Professor Reid, were submitted to me for examination. The report on them will be published also as an appendix to Professor Reid's paper, soon to appear in the National Geographic Magazine. The species observed are recorded in their proper systematic position in the present paper.

The latest work dealing with fossil flora of Alaska, and this only incidentally, is the United States Geological Survey correlation paper on the Neocene by W. H. Dall and G. D. Harris.¶ These authors review at length all fossil-bearing horizons in Alaska, and on a map accompanying the work color each locality geologically. They speak of plant beds in various places.

Herendeen bay, the locality affording the specimens that form the basis of this paper, is on the northern side of the Alaskan peninsula and forms a branch of Port Möller (latitude 55° 40′; longitude 160° 40′ ±). The plants were collected July 28, 1890, by Mr Charles H. Townsend, resident naturalist of the United States Fish Commission Steamer *Albatross.*

Mr Townsend has furnished the following copy of his notes relating to their occurrence:

*July 28, 1890.*—In making a tramway to the new coal mine just opened here (Herendeen bay), one of the slaty cuttings exposed a large deposit of fossil leaves and ferns, about a mile from the beach, at the head of a little valley among the hills and within a few hundred yards of the mine itself. We visited the place twice and succeeded in getting a considerable quantity of specimens. Coal veins crop out in several places in the region of this bay. The first output of the new mine is now being used in the furnaces of the *Albatross*, but it is from near the surface and rather slaty.

Mr Townsend further adds:

The country is mountainous and treeless, but covered with bushes and smaller vegetation. It is in general volcanic and there are lofty peaks, one of which, Pavloff, has been seen smoking.

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* Proc. U. S. Nat. Mus., vol. XI, 1888, pp. 31–33, pl. XVI, figs. 1–6, and pl. x, fig 4.

† Zeitschr. d. D. geol. Gesell., vol. XXXVIII, 1886, pp. 483–485.

‡ Fifty miles north of the head of Lynn canal, in southwestern Alaska.

§ This is really extra-limital, but has been included as being more nearly related to the Alaskan province than to any other.

‖ National Geographic Magazine, vol. IV, 1893, pp. 75–78, figs 4, 5.

¶ Bull. U. S. Geol Survey, no. 84, pp. 232–268, pl. III.

The material in which the plants are preserved is a fine argillaceous sandstone, very well fitted for retaining the impressions. The vegetal remains are in most cases very numerous, even on small fragments of matrix.

## SYSTEMATIC ENUMERATION OF SPECIES*

### *ALGÆ*

#### *Chondrites filiciformis*, Lesquereux.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 32, pl. XVI, fig. 1.

Cape Lisburn; H. D. Woolfe.

#### *Chondrites heeri*, Eichwald.

EICHWALD, Geognost.-Palæontolog., Bemerk. ü. Halbinsel Mangischlak und Aleutischen Inseln; Saint Petersburg, 1871, p. 111, pl. IV, fig. 1.
*Chondrites* sp. HEER, Fl. Foss. Alask., p. 21, pl. x, fig 5.

Kachemak bay; H. Furuhjelm.

### *EQUISETACEÆ*

#### *Equisetum globulosum*, Lesquereux.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882, p. 444; Cret. and Tert. Flora, p. 222, pl. XLVIII, fig. 3.

This species was obtained by Dr W. H. Dall, but the exact locality is not given. As the only localities from which he obtained fossil plants were Cook inlet, Unga island, and Chugachik bay, it most probably came from one of these.

#### *Calamites ambiguus*, Eichwald.

EICHWALD, Geognost.-Palæontolog., Bemerk. ü. Halbinsel Mangischlak und Aleutischen Inseln; Saint Petersburg, 1871, p. 114, pl. IV, fig. 9.

Northeastern coast of Alaska north of cape Jaklök and south of a small stream bearing the same name; Eichwald.

### *FILICES*

#### *Pecopteris denticulata*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. XI, 1888, p. 32.

Cape Lisburn; H. D. Woolfe.

#### *Pteris sitkensis*, Heer.

HEER, Fl. Foss. Alask., p. 21, pl. I, fig. 7*a*; EICHWALD, Geognost.-Palæontolog., Bemerk. ü. Halbinsel Mangischlak, und Aleutischen Inseln; Saint Petersburg, 1871, p. 112.

Island of Kuiu, near Sitka; H. Furuhjelm.

#### *Osmunda doroschkiana*, Göppert.

GÖPPERT, Abhandl. d. Schles. Gesell. f. Vaterländ-Cult., 1861, pt. II, p. 203; EICHWALD, Geognost.-Palæontolog., Bemerk. ü. Halbinsel Mangischlak und Aleutischen Inseln, p. 112, pl. IV, figs. 2, 3.
*Osmunda torelli*, HEER, LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 444, pl. VI, figs. 3-6.

Unga island; Lieutenant von Doroshin. Coal Harbor, Unga island; W. H. Dall.

*The compiled descriptions of the old species as well as descriptions of the new forms are omitted from the following list. They may be found in the Proc. U. S. Nat. Mus, vol. XVII, pp. 211-231. The bibliographic citations refer exclusively to the occurrence of the various species in Alaska, and are not to be regarded as indicating the complete synonymy.

*Aspidium œrstedi*, Heer.

Lesquereux, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 32.

Cape Lisburn; H. D. Woolfe.

*Asplenium foersteri*, Debey and Ettingshausen.

Lesquereux, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 32.

Cape Lisburn; H. D. Woolfe.

*CONIFERÆ*

*Asplenium dicksonianum*, Heer.

Lesquereux, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 32.

Cape Lisburn; H. D. Woolfe.

*Pinus ! staratschini*, Heer.

Lesquereux, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 32.

Cape Lisburn; H. D. Woolfe.

*Pinus*, species.

Heer, Fl. Foss. Alask., p. 23, pl. i, fig. 11.

Port Graham; H. Furuhjelm.

*Sequoia langsdorfii* (Brongniart), Heer.

Heer, Fl. Foss Alask., p. 23, pl. i, fig. 10.

Port Graham and Neniltschik; H. Furuhjelm. Herendeen bay; Charles H. Townsend.

*Sequoia spinosa*, Newberry.

Newberry, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 504; plates, pl. liii, figs 4, 5, *ined.*

Cook inlet; Captain Howard, U. S. Navy.

*Taxodium distichum miocenum*, Heer.

Heer, Fl. Foss. Alask., p. 21, pl. i, fig. 6; iii, fig. 11*c*; iv, fig. 5 *f*, *c*.

Port Graham and Neniltschik; H. Furuhjelm. Near Sitka; Lieutenant von Doroshin. Herendeen bay; Charles H. Townsend.

*Taxodium tinajorum*, Heer.

Heer, Fl. Foss. Alask., p. 22, pl. i, figs. 1–5.

Port Graham; H. Furuhjelm.

*Taxodium tinajorum*, Heer, var.

Eichwald, Geognost.-Palæontolog., Bemerk. ü. Halbinsel Mangischlak und Aleutischen Inseln; Saint Petersburg, 1871, p. 116, pl. iv, fig. 4.

Port Graham (English bay) and Neniltschik; Lieutenant H. von Doroshin.

*Glyptostrobus europæus* (Brongniart), Heer.

Heer, Fl. Foss. Alask., p. 22, pl. i, fig. 7 *b*, *f*; iii, figs. 10, 11.

Kuiu island, near Sitka; Lieutenant von Doroshin. Neniltschik; H. Furuhjelm. Herendeen bay, Charles H. Townsend.

*Taxites olriki*, Heer.

Heer, Fl. Foss. Alask., p. 23, pl. i, fig. 8; ii, 5*b*.

Port Graham; H. Furuhjelm.

*Thuites* (*Chamæcyparis*) *alaskensis*, Lesquereux.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 445, pl. vi, figs. 7-9.

Coal Harbor, Unga island; Dr W. H. Dall.

*Gingko multinervis*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 31, pl. xvi, fig. 6.

Cape Lisburn; H. D. Woolfe.

*Gingko adiantoides* (Unger), Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. x, 1887, p. 35.

Sitka; E. W. Nelson (?).

A single small doubtful fragment from Herendeen bay. Collected by Charles H. Townsend.

*Baiera palmata*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 31, pl. xvi, figs. 4, 5.

Cape Lisburn; H. D. Woolfe.

*Picea sitchensis*, Carr.

HERRICK, Nat. Geog. Mag., vol. iv, 1892, pp. 75-78, figs. 4, 5; KNOWLTON, Notes on the Examination of a Collection of Interglacial Wood from Muir Glacier, Alaska, MS.

Muir glacier; Harry Fielding Reid.

*Tsuga mertensiana*, Carr.

KNOWLTON, Notes on the Examination of a Collection of Interglacial Wood from Muir Glacier, Alaska, MS.

Muir glacier; Harry Fielding Reid.

*Cupressinoxylon erraticum*, Mercklin.

FELIX, Zeitschr. d. D. geol. Gesell., vol. xxxviii, 1886, p. 484.

Copper island, southwestern part of Bering sea; Dr Krause.

*Pinites pannonicus* (Unger), Göppert.

GÖPPERT, Abhandl. d. Schles. Gesell., 1861, p. 203; HEER, Fl. Foss. Alask., p. 23.

Southwestern end of Unga island; Lieutenant von Doroshin.

*Pityoxylon inæquale*, Felix.

FELIX, Zeitschr. d. D. geol. Gesell., vol. xxxviii, 1886, p. 483, pl. xii, fig. 3.

Basalt mountain, south of Danaáku; Dr Krause.

*CYCADACEÆ*

*Zamites alaskana*, Lesquereux.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 32, pl. x, fig. 10.

Cape Lisburn; H. D. Woolfe.

*Podozamites latipennis*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. xi, 1888, p. 31, pl. xvi, figs. 2, 3.

Cape Lisburn; H. D. Woolfe.

*GRAMINEÆ*

*Phragmites alaskana*, Heer.

HEER, Fl. Foss. Alask., p. 24, pl. i, fig. 12.

Port Graham; H. Furuhjelm.

*Poacites tenue-striatus*, Heer.

HEER, Fl. Foss. Alask., p. 24, pl. I, fig. 14; EICHWALD, Geognost.-Palæontolog., Bemerk. ü. Halbinsel Mangischlak und Aleutischen Inseln; Saint Petersburg, 1871, p. 114, pl. IV, fig. 7.

Port Graham; H. Furuhjelm. Herendeen bay; Charles H. Townsend.

*CYPERACEÆ*

*Carex servata*, Heer.

HEER, Fl. Foss. Alask., p. 24, pl. I, figs. 13, 13 *c*, *d*.

Port Graham; H. Furuhjelm. Herendeen bay; Charles H. Townsend.

*Carex* (leaves of).

LESQUEREUX, Proc. U. S. Nat. Mus., vol. x, 1887, p. 36.

Sitka; E. W. Nelson (?).

It is possible that this may be the *C. servata* of Heer, but as it is neither figured nor described I have retained it as probably separate.

*ALISMACEÆ*

*Sagittaria pulchella*, Heer.

HEER, Fl. Foss. Alask., p. 25, pl. I. fig. 15.

Neniltschik; H. Furuhjelm.

*Sagittaria*, species.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. x, 1887, p. 37.

Sitka; E. W. Nelson (?).

*IRIDACEÆ*

*Irites alaskana*, Lesquereux.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. x, 1887, p. 36.

Cape Lisburn; H. D. Woolfe.

*SALICACEÆ*

*Populus latior*, Heer.

HEER, Fl. Foss. Alask., p. 25, pl. II, fig. 4.

Port Graham; H. Furuhjelm.

*Populus glandulifera*, Al. Braun.

HEER, Fl. Foss. Alask., p. 26, pl. II, figs. 1, 2.

Port Graham; H. Furuhjelm.

*Populus balsamoides*, Göppert.

HEER, Fl. Foss. Alask., p. 26, pl. II, fig. 3.
*Populus exima*, GÖPPERT, Tert. fl. v. Schossnitz, p. 23; Abhandl. Schles., Gesell., 1861, p. 203.

Port Graham; H. Furuhjelm. Kutznahoo, near Sitka; Lieutenant von Doroshin.

*Populus zaddachi*, Heer.

HEER, Fl. Foss. Alask., p. 26, pl. II, fig. 5*a*.

Port Graham; H. Furuhjelm.

*Populus leucophylla*, Unger.

HEER, Fl. Foss. Alask., p. 26. pl. II, fig. 6.
*Populus acerifolia*, NEWBY., Later extinct Floras of North America, p. 65.

Reported by Heer, but no locality given for Alaska.

*Populus arctica*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 447, pl. IX, fig. 2.

Chignik bay; Dr W. H. Dall.

*Populus richardsoni*, Heer.

LESQUEREUX, Proc. U S. Nat. Mus., vol. v, 1882 (1883), p. 441, pl. IX, fig. 1.

Chignik bay; Dr W. H. Dall.

*Salix varians*, Göppert.

HEER, Fl. Foss. Alask., p. 27, pl. II, fig. 8: III, figs. 1-3.
GÖPPERT, Tert. fl. v. Schlossnitz, p. 26; Abhandl. Schles., Gesell., 1861, p. 205.

Port Graham and Neniltschik; H. Furuhjelm.

*Salix macrophylla*, Heer.

HEER, Fl. Foss. Alask., p. 27, pl. II, fig. 9; EICHWALD, Geognost.-Palæontolog., Bemerk. ü. Halbinsel Mangischlak und Aleutischen Inseln; Saint Petersburg, 1871, p. 113, pl. IV, fig. 5.

Port Graham; H. Furuhjelm.

*Salix lavateri*, Heer.

HEER, Fl. Foss. Alask., p. 27, pl. II, fig. 10.

Port Graham; H. Furuhjelm.

*Salix ræana*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 447, pl. VIII, fig. 6.

Cook inlet; Dr W. H. Dall.

*Salix integra*, Göppert.

GÖPPERT, Abhandl. Schles. Gesell., 1861, p. 202; *ibid.*, 1867, p. 50.

Neniltschik; Lieutenant von Doroshin.

*Salix minuta*, Knowlton.

KNOWLTON, Proc. U. S. Nat. Mus., vol. XVII, 1894, p. 218, pl. IX, fig. 1.

Herendeen bay; Mr Charles H. Townsend, of the United States Fish Commission steamer *Albatross*.

CUPULIFERÆ

*Fagus antipofii*, Heer.

HEER, Fl. Foss. Alask., p. 30, pl. V, fig. 4*a*; VII, figs. 4-8; VIII, fig. 1.

Port Graham; H. Furuhjelm.

*Fagus macrophylla*, Unger.

HEER, Fl. Foss. Alask., p. 31, pl. VIII, fig. 2.

Port Graham; H. Furuhjelm.

*Fagus feroniæ*, Unger.

HEER, Fl. Foss. Alask., p. 31, pl. VI, fig. 9.

Port Graham; H. Furuhjelm.

*Fagus deucalionis*, Unger.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882, p. 447 (1883).

Kachemak bay, Cook inlet; Dr William H. Dall.

*Castanea ungeri*, Heer.

HEER, Fl. Foss. Alask., p. 32, pl. VII, figs. 1-3.

Port Graham; H. Furuhjelm. Keku island, Indian archipelago (?)

*Quercus pseudocastanea*, Göppert.

Heer, Fl. Foss. Alask., p. 32, pl. vi, figs. 3–5.

Port Graham; H. Furuhjelm.

*Quercus furuhjelmi*, Heer.

Heer, Fl. Foss. Alask., p. 32, pl. v, fig. 10; vi, figs. 1, 2.

Port Graham; H. Furuhjelm.

*Quercus pandurata*, Heer.

Heer, Fl. Foss. Alask., p. 33, pl. vi, fig. 6.

Port Graham; H. Furuhjelm.

*Quercus chamissonis*, Heer.

Heer, Fl. Foss. Alask., p. 33, pl. vi, figs. 7, 8.

Port Graham; H. Furuhjelm.

*Quercus dallii*, Lesquereux.

Lesquereux, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 446, pl. viii, figs. 2–5; Cret. and Tert. Flora, p. 259.

Cook inlet; Dr William H. Dall.

*Corylus macquarrii* (Forbes), Heer.

Heer, Fl. Foss. Alask., p. 29, pl. iii, fig. 9, iv, figs. 1–5, 9; Eichwald, Geognost.-Palæontolog., Bemerk. ü Halbinsel Mangischlak und Aleutischen Inseln; Saint Petersburg, 1871, p. 113, pl. iv, fig. 6; Knowlton, Proc. U. S. Nat. Mus., vol. xvii, 1894, pl. ix, fig. 4.

Port Graham and Neniltschik; H. Furuhjelm. Kuiu island near Sitka; Lieutenant von Doroshin. Unga island; Dr William H. Dall. Herendeen bay; Charles H. Townsend.

*Corylus macquarrii* var. *macrophylla*, Heer.

Heer, Fl. Foss. Alask., p. 30, pl. iv, figs. 6, 7.

Port Graham; H. Furuhjelm.

*Carpinus grandis*, Unger.

Heer, Fl. Foss. Alask., p. 29, pl. ii, fig. 12; Lesquereux, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 446.

Kachemak bay, Cook inlet; Dr William H. Dall. Port Graham; H. Furuhjelm.

*Alnus kefersteinii* (Göppert), Unger.

Heer, Fl. Foss. Alask., p. 28, pl. iii, figs. 7, 8.

Neniltschik; H. Furuhjelm.

*Alnus kefersteinii* (Göppert), var.

Heer, Fl. Foss. Alask., p. 28, pl. v, fig. 9.

Port Graham (?); H. Furuhjelm.

*Alnus alaskana*, Newberry.

Newberry, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 509; Plates, pl. xlviii, fig. 8.

Kootzahoo archipelago (latitude 57° 35′, longitude 134° 19′); U. S. steamer *Saginaw* (February 18, 1869).

*Alnus grandifolia*, Newberry.

Newberry, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 509.

Cook inlet; Captain Howard, U. S. Navy.

*Alnus corylifolia*, Lesquereux.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 446, pl. VII, figs. 1-4; Cret. and Tert. Flora, p. 258.

Kachemak bay, Cook inlet; Dr William H. Dall.

*Alnus rubra*, Bongard.

A branch of this species found protruding from a gravel bank beneath an ice-sheet 70 feet in thickness, on the eastern moraine of Muir glacier. Collected by Miss Eliza R. Scidmore, of Washington, D. C.

*Betula prisca*, Ettingshausen.

HEER, Fl. Foss. Alask., p. 28, pl. V, figs. 3-6.

Port Graham and Neniltschik; H. Furuhjelm.

*Betula grandifolia*, Ettingshausen.

HEER, Fl. Foss. Alask., p. 29, pl. V, fig. 8.

Port Graham; H. Furuhjelm.

*Betula alaskana*, Lesquereux.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 446, pl. VI, fig. 14; Cret. and Tert. Flora, p. 258.

Chignik bay, Alaska peninsula; Dr William H. Dall.

*MYRICACEÆ*

*Myrica banksiæfolia*, Unger.

HEER, Fl. Foss. Alask., p. 28, pl. II, fig. 11.

Port Graham; H. Furuhjelm.

*Myrica* (*Comptonia*) *cuspidata* (Lesquereux), Dawson.

*Comptonia suspidata*, LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 445, pl. VI, figs. 10-12; Cret. and Tert. Flora, p. 258.

*Myrica (Comptonia) cuspidata* (LESQUEREUX), DAWSON, Trans. Roy. Soc. Canada, 1890, p. 80, fig. 9.

Coal harbor, Unga island; Dr W. H. Dall.

*Myrica* (*Comptonia*) *præmissa*, Lesquereux, sp.

*Comptonia præmissa*, LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882, p. 445, pl. VI, fig. 13.

Coal harbor, Unga island; Dr W. H. Dall.

*Myrica vindobonensis* (Ettingshausen), Heer.

HEER, Fl. Foss. Alask., p. 27, pl. III, figs. 4, 5.

Neniltschik; H. Furuhjelm.

*JUGLANDACEÆ*

*Juglans acuminata*, Al. Braun.

HEER, Fl. Foss. Alask., p. 38, pl. IX, fig. 1.

Port Graham; H. Furuhjelm.

*Juglans nigella*, Heer.

HEER, Fl. Foss. Alask., p. 38, pl. IX, figs. 2-4.

Port Graham; H. Furuhjelm.

*Juglans picroides*, Heer.

HEER, Fl. Foss. Alask., p. 39, pl. IX, fig. 5.

Port Graham; H. Furuhjelm.

*Juglans woodiana*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 449.

Chignik bay; Dr W. H. Dall.

*Juglans townsendi*, Knowlton.

KNOWLTON, Proc. U. S. Nat. Mus., vol. XVII, 1894, p. 222, pl. IX, fig. 5.

Herendeen bay; Charles H. Townsend.

*URTICACEÆ*

*Ficus alaskana*, Newberry.

NEWBERRY, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 512; Plates, pl. LII, fig. 1; LV, figs. 1, 2.

Cook inlet and Admiralty inlet; Captain Howard, United States Navy.

*Ficus membranacea*, Newberry.

NEWBERRY, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 512; Plates, pl. LIX, fig. 2.

Cook inlet; Captain Howard, United States Navy.

*Planera Ungeri*, Ettingshausen.

HEER, Fl. Foss. Alask., p. 34, pl. v, fig. 2.

Port Graham; H. Furuhjelm.

*Ulmus plurinervia*, Unger.

HEER, Fl. Foss. Alask., p. 34, pl. v, fig. 1.

Port Graham; H. Furuhjelm.

*Ulmus sorbifolia*, Göppert.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 447, pl. IX, fig. 3; Cret. and Tert. Flora, p. 260.

Kachemak bay, Cook inlet; Dr William H. Dall.

*EBENACEÆ*

*Diospyros stenosepala*, Heer.

HEER, Fl. Foss. Alask., p. 35, pl. VIII, figs. 7, 8.

Neniltschik; H. Furuhjelm.

*Diospyros alaskana*, Schimper.

*Diospyros alaskana*, SCHIMPER, Traité d. Pal. Vég., vol. II, p. 945.
*Diospyros lancifolia*, LESQUEREUX, in Heer, Fl. Foss. Alask., p. 35, pl. III, fig. 12.

Neniltschik; H. Furuhjelm.

*Diospyros anceps*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 448, pl. X, figs. 1, 2; Cret. and Tert. Flora, p. 261.

Cook inlet; Dr William H. Dall.

*OLEACEÆ*

*Fraxinus herendeenensis*, Knowlton.

KNOWLTON, Proc. U. S. Nat. Mus., vol. XVII, 1894, p. 224, pl. IX, fig. 7.

Herendeen bay; Charles H. Townsend.

*ERICACEÆ*

*Andromeda grayana*, Heer.

HEER, Fl. Foss. Alask., p. 34, pl. VIII, fig. 5.

Port Graham; H. Furuhjelm.

*Vaccinium friesii*, Heer.

HEER, Fl. Foss. Alask., p. 35, pl. VIII, fig. 4.

Port Graham; H. Furuhjelm.

*Vaccinium reticulatum*, Al. Braun.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 448, pl. x, figs. 3-5; Cret. and Tert. Flora, p. 261.

Cook inlet; Dr William H. Dall.

*CAPRIFOLIACEÆ*

*Viburnum nordenskiöldi*, Heer.

HEER, Fl. Foss. Alask., p. 36, pl. III, fig. 13.

Neniltschik; H. Furuhjelm.

*CORNACEÆ*

*Nyssa arctica* (?), Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 447; Cret. and Tert. Flora, p. 261.

Unga island; Dr William H. Dall.

*Cornus orbifera*, Heer.

LESQUEREUX, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 448, pl. x, fig. 6; Cret. and Tert. Flora, p. 262.

Cook inlet; Dr William H. Dall.

*ARALIACEÆ*

*Hedera auriculata*, Heer.

HEER, Fl. Foss. Alask., p. 36, pl. IX, fig. 6.

Port Graham; H. Furuhjelm.

*ONAGRACEÆ*

*Trapa borealis*, Heer.

HEER, Fl. Foss. Alask., p. 38, pl. VIII, figs. 9-14.

Port Graham; H. Furuhjelm.

*HAMAMELIDACEÆ*

*Liquidambar europæum*, Al. Braun.

HEER, Fl. Foss. Alask., p. 25, pl. II, fig. 7.

Port Graham; H. Furuhjelm.

*ROSACEÆ*

*Spiræa andersoni*, Heer.

HEER, Fl. Foss. Alask., p. 39, pl. VIII, fig. 3.

Port Graham; H. Furuhjelm.

*Prunus variabilis*, Newberry.

NEWBERRY, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 509; Plates, pl. LII, figs. 3-5.

Cook inlet; Captain Howard, United States Navy.

*SAPINDACEÆ*

*Acer macropterum*, Heer.

HEER, Fl. Foss. Alask., p. 37, pl. IX, figs. 7-9.

Port Graham; H. Furuhjelm.

*Acer trilobatum productum* (Al. B.), Heer.

Knowlton, Proc. U. S. Nat. Mus., vol. xvii, 1894, p. 227, pl. ix, fig. 3.

Herendeen bay; Charles H. Townsend.

*ANACARDIACEÆ*

*Rhus frigida*, Knowlton.

Knowlton, Proc. U. S. Nat. Mus., vol. xvii, 1894, p. 227, pl. ix, fig. 6.

Herendeen bay; Charles H. Townsend.

*VITACEÆ*

*Vitis crenata*, Heer.

Heer, Fl. Foss. Alask., p. 36, pl. viii, fig. 6.

Port Graham; Furuhjelm.

*Vitis rotundifolia*, Newberry.

Newberry, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 513; Plates, pl. li, fig. 2: lii, fig. 3.

Almiralty inlet; Captain Howard, United States Navy.

*CELASTRACEÆ*

*Elæodendron helveticum*, Heer.

Lesquereux, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 449, pl. ix, fig. 4; Cret. and Tert. Flora, p. 263.

Coal Harbor, Unga island; Dr William H. Dall.

*Celastrus borealis*, Heer.

Heer, Fl. Foss. Alask., p. 37, pl. x, fig. 4.

Port Graham; H. Furuhjelm.

*ILICINEÆ*

*Ilex insignis*, Heer.

Heer, Fl. Foss. Alask., p. 37, pl. x, fig. 1.

Port Graham; H. Furuhjelm.

*RHAMNACEÆ*

*Zizyphus townsendi*, Knowlton.

Knowlton, Proc. U. S. Nat. Mus., vol. xvii, 1894, p. 229, pl. ix, figs. 8, 9.

Herendeen bay; Charles H. Townsend (for whom the species is named).

*Paliurus colombi*, Heer.

Knowlton, Proc. U. S. Nat. Mus., vol. xvii, 1894. p. 230, pl. ix, fig. 2.

Herendeen bay; Charles H. Townsend.

*TILIACEÆ*

*Tilia alaskana*, Heer.

Heer, Fl. Foss. Alask., p. 36, pl. x, figs. 2, 3.

Port Graham; H. Furuhjelm.

*MAGNOLIACEÆ*

*Magnolia nordenskiöldi*, Heer.

Lesquereux, Proc. U. S. Nat. Mus., vol. v, 1882 (1883), p. 448, pl. x, figs. 7-9; and Cret. Tert. Flora, p. 262.

Chignik bay; Dr W. H. Dall.

*Phyllites arctica*, Knowlton.

KNOWLTON, Proc. U. S. Nat. Mus., vol. XVII, 1894, p. 230, pl. IX, figs. 10, 11.

Herendeen bay; Charles H. Townsend.

## DISCUSSION OF THE FLORA.

The fossil flora of Alaska as presented in this paper embraces 115 forms. Of this number, one is regarded as extra-limital and three are interglacial, being found also living about Muir glacier. Of the 111 forms remaining, no less than 46 are peculiar to Alaska, leaving 64 forms having an outside distribution. On removing the nine species found at cape Lisburn about which there is little question of age, we have remaining only 55 species, or a little less than fifty per cent, from which to determine the bearing of the plants on the question of age.

An examination of the distribution gives the following numerical results: The Laramie has three species, of which one is doubtful; the post-Laramie beds of Colorado have 10 species; the Livingston beds of Montana six species; the Fort Union beds 16 species, of which one is doubtful; the Green river group nine species, of which three are in doubt; the Mackenzie river deposits 11 species; British Columbia has seven species in the Miocene and four in the Laramie, with two common to both; California, represented by the auriferous gravels and allied formations, has 17 species, of which three are in doubt; the Eocene (Alum bay, etc) six species; the Greenland Miocene, as represented at Disco island, Atanekerdluk, etc, has 29 species; the Miocene of Spitzbergen 20 species; the island of Sachalin (Siberia) 23 species; Sinigalia (Italy) 12 species; the so-called Baltic Miocene 13 species; Œningen 20 species; Oligocene 11 species; Miocene 33 species; Pliocene 15 species.

By combining a number of the above localities which may be legitimately taken together, still more impressive results are obtained. Thus, by combining the post-Laramie beds of Colorado with the Livingston beds of Montana, 13 species are found to be common to Alaska. The union of the Mackenzie river and Fort Union deposits gives 21 species common to Alaska, while Greenland, Spitzbergen, and Sachalin have no less than 39 species out of the 55 species from Alaska. This last result shows, if any dependence is to be placed on fossil plants, that the floras of Alaska, Greenland, Spitzbergen and the island of Sachalin are so closely related as to lead to the unavoidable conclusion that they grew under similar conditions and were synchronously deposited. The localities enumerated show that the circumpolar flora at that time was practically similar and continuous.

The coal-bearing beds of southeastern Alaska, to which Dall has given the name Kenai group, are perhaps best exhibited on the shores of Kachekmak bay, Kenai peninsula, and Cook inlet. They appear, however, to be widely spread over British Columbia and over the coast of Alaska and its neighboring islands. According to Dall * the sequence of the rocks, when undisturbed, appears to be, in descending order, as follows:

1. Soil and Pleistocene beds.
2. Brown Miocene sandstone, with marine shells, cetacean bones and water-worn teredo-bored fossil wood. (Astoria group, Nulato sandstones, Crepidula bed.)
3. Beds of conglomerate, brown and iron-stained, alternating with gravelly and sandy layers, the finer beds containing fossil leaves of Sequoia and other vegetable remains. (Kenai group, Unga beds.)

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* Bull. U. S. Geol. Survey, no. 84, 1892, pp. 232–233.

4. Bluish sandy slates and shales with a rich Miocene plant flora, interstratified with beds of indurated gravel, fossil wood and lignitic coal. (Kenai group.)

5. Metamorphic quartzites and slaty rocks, illustrating the geologic series probably from the Jurassic to the upper Cretaceous, with perhaps part of the lower Eocene. (Chico-Tejon.)

6. Granite and syenite in massive beds, usually without mica and apparently in most instances forming the "backbone" of the mountain ridges or islands, but occasionally occurring in intrusive masses. (Shumagin granite.)

The geologic age of these coal-bearing rocks, from which most of the plants enumerated in this paper came, has usually been regarded as Miocene. Heer, who worked up the first considerable collection of plants, referred them unhesitatingly to this horizon, and regarded them as the equivalent of the Miocene beds of Greenland, Spitzbergen, the Braunkohl of eastern Prussia and the lower Molasse of Switzerland. Lesquereux and (at first) Newberry do not appear to have seriously questioned their Miocene age. Of the 73 species enumerated by Lesquereux in his latest publication on Alaskan plants, 21 are found in Greenland and Spitzbergen and 31 in the Miocene of other parts of the world. These considerations show that the fossil flora of Alaska is inseparably connected with that of the Disco island and Atanekerdluk beds of Greenland and the so-called arctic Miocene of Spitzbergen and Sachalin. Whatever is decided concerning them must apply with equal force to Alaska.

Mr J. Starkie Gardner appears to have been the first to question the Miocene age of the Greenland beds,* or rather of the Arctic floras in general. The sequence of British Eocene floras is almost unbroken, and in studying them and their relations to the Miocene flora he was led to important conclusions. He says:

There is no great break in passing from one to the other (Eocene to Miocene) when we compare them over many latitudes, and but little change beyond that brought about by altered temperature or migration. But if Tertiary floras of different ages are met with in one area, great changes, on the contrary, are seen, and these are mainly due to progressive modifications in climate and to altered distribution of land. Imperceptibly, too, the tropical members of the flora disappeared; that is to say, they migrated; for most of their types, I think, actually survive at the present day, many but slightly altered. Then the subtropical members decreased, and the temperate forms, never quite absent even in the middle Eocenes, preponderated. As decreasing temperature drove the tropical forms south, the more northern must have pressed more closely upon them. The northern Eocene, or the temperate floras of that period, must have pushed, from their home in the far north, more and more south as climates chilled, and at last, in the Miocene time, occupied our latitudes. The relative preponderance of these elements, I believe, will assist in determining the age of Tertiary deposits in Europe more than any minute comparisons of species. Thus it is useless to seek in the Arctic regions for Eocene floras as we know them in our latitudes, for during the Tertiary period the climatic conditions of the earth did not permit their growth there. Arctic floras of temperate, and therefore Miocene, aspect are in all probability of Eocene age, and what has been recognized as a newer or Miocene facies is due to their having been first studied in Europe in latitudes which only became fitted for them in Miocene times.

This change of view as to the age of the so-called Arctic Miocene, as proposed by Gardner, has already received considerable confirmation from American paleobotanists, and while it can hardly be regarded as settled, it may be accepted as extremely probable.

Dr J. S. Newberry, in one of his latest publications, said: †

I called the Fort Union group Miocene because I identified it with the plant-bearing beds of Mackenzie river, Disco island, Greenland, etc, of which the flora had been studied by Professor

* British Eocene flora, part I, 1879, p. 8.

† Trans. N. Y. Acad. Sci., vol. IX, p. 1 of reprint.

Oswald Heer and was by him called Miocene. This flora, to which I shall again refer, has since been shown by Mr J. Starkie Gardner to be Eocene. The Fort Union flora has many species in common with the Eocene beds of the island of Mull, Bourenemouth, etc, and holds undoubtedly the same position.

On this same point Sir William Dawson says: *

I have, also, while writing out the above notes for publication, received the paper of the same author (Gardner) on the Eocene beds of Ardtun, in Mull, and am fully confirmed thereby in the opinion derived from the papers of the Duke of Argyll and the late Professor E. Forbes that the Mull beds very closely correspond in age with the Laramie. The *Felicites hebridica* of Forbes is our *Onoclea sensibilis*. The species of *Gingko*, *Taxus*, *Sequoia* and *Glyptostrobus* correspond, and we have now probably found a *Podocarpus*, as noted above. The *Platanites hebridica* is very near to our great *Platanus nobilis*. *Corylus macquarrii* is common to both formations, as well as *Populus arctica* and *P. richardsoni*, while many of the other exogens are generically the same, and very closely allied. These Ardtun beds are regarded by Mr Gardner as lower Eocene, or a little older than the Gelinden series of Saporta, and nearly of the same age with the so-called Miocene of Atanekerdluk, in Greenland. Dr G. [M.] Dawson and the writer have, ever since 1875, maintained the lower Eocene age of our Laramie, and of the Fort Union group of the northwestern United States, and the identity of their flora with that of Mackenzie river and the upper beds of Greenland, and it is very satisfactory to find that Mr Gardner has independently arrived at similar conclusions with respect to the Eocene of Great Britain.

Dr Dall is rather more cautious in adopting the Eocene age of these beds. He says: †

I have already pointed out the probability that, if Miocene at all, the leaf beds of Greenland referred to would be synchronous with that geological epoch during which the old Miocene warm-water invertebrate fauna of the Atlantic coast penetrated as far north as New Jersey.

Since that time it is highly improbable that any temperate conditions such as the flora would indicate for the Atane period, have obtained in the latitude of Greenland. In other words, the Greenland beds are not later than the old Miocene, though this does not preclude a reference of them to an older horizon than the Miocene, for during the Eocene also the conditions in the extreme north might have been favorable to such a flora.

In Alaska, at Cook inlet, at Unga island, at Aka, and at Nulato, in the Yukon valley, we find the leaf beds of the Kenai group immediately and conformably overlain by marine beds containing fossil shells, which are common to the Miocene of Astoria, Oregon, and to middle and southern California.

It is then certain that the Kenai leaf beds immediately preceded and their deposition terminated with the depression (probably moderate in vertical range) which enabled the marine Miocene fauna to spread over part of the antecedently dry land. Further researches along the Alaskan coast will doubtless enable us to determine whether the leaf beds themselves are underlain by marine Eocene beds or not. We know that the *Aucella* beds underlie the Kenai series, but whether there are any beds representing the marine phase of the Eocene between them is yet uncertain, though very probable. * * *

What may be considered as reasonably certain is that the period during which in the arctic regions the last temperate flora flourished was in a general way the same for all parts of the arctic. It would seem highly improbable that a temperate climate should exist in the Spitzbergen and not at the same time in Greenland and Alaska, or *vice versa*. If Alaska was covered by the sea at this time, we should find a temperate marine fauna; if it was dry land, a temperate flora; and so with the other arctic localities; and these indications should, it would seem, represent an identical and synchronic phase of geologic history in the arctic regions.

The distribution and character of this group have been somewhat fully discussed because, up to very recently, authorities were practically unanimous in referring it to the Miocene, a view which cannot yet be said to be definitely refuted. But when we consider how the Eocene Astoria bed is immediately and conformably overlain at Astoria by shales and sandstones, and that the latter conformably and immediately in like manner overlies the Kenai group, it must be conceded that the view that the latter is probably of Eocene age does not appear unreasonable.

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* Trans. Roy. Soc. Canada, 1887, p. 36.

† *Op. cit.*, pp. 251–252.

Following out the argument suggested by Newberry and Dawson, that is, the relation existing between the plants of Alaska and Mackenzie river, and these in turn with the Canadian Laramie and the Fort Union group, we have important confirmatory evidence. The flora of the Mackenzie river beds, as worked out by Heer,* Schrœter,† and Dawson,‡ now numbers 30 species, and of these no less than 12, or 40 per cent, are found in Alaska. The 12 species common to Alaska are not rare or poorly defined in the Alaskan flora, but are in the main well marked and readily determinable forms, most of which are very abundant in individuals, as for example *Sequoia langsdorfii*, *Taxodium distichum miocenum*, *Glyptostrobus europæus* or *ungeri*, *Corylus macquarrii*, *Populus arctica*, etc. A single species, *Pteris sitkensis*, is confined to these two localities, and a number of other species, though known by different names, are closely allied, if not identical. There can be, therefore, little doubt as to the close relationship between the Alaska and the Mackenzie river deposits.

The Mackenzie river flora, as already suggested, is in like manner closely related with the Canadian upper Laramie, or Fort Union group, as it is called in the United States, about 30 per cent of the Mackenzie species being common to the two.

On further working out the distribution, we find that 16 of the 55 Alaskan species are found in the Fort Union of the United States. By combining the species common to Mackenzie river, Canadian upper Laramie, and Fort Union, we have 22 or 23 of these species also found in the Alaskan beds.

Without going further into the subject, which indeed the present state of our knowledge will hardly warrant, it is safe to say with Sir William Dawson that "There can scarcely be any doubt that the flora of the upper Laramie, of the Atanekerdluk series in Greenland, and of the Spitzbergen and Alaska Tertiaries corresponds with the Eocene of Europe, and is also identical with Fort Union flora of the Missouri region, formerly regarded as Miocene."

A less extended abstract of this paper is published in The American Journal of Science, volume xlvii, page 137.

A brief paper by the President was then presented:

### *NEW DISCOVERIES OF CARBONIFEROUS BATRACHIANS*

BY SIR J. WILLIAM DAWSON

The paper is published in the Canadian Record of Science, January, 1894.

The following paper was read by J. Stanley-Brown:

### *CENOZOIC GEOLOGY ALONG THE APALACHICOLA RIVER*

BY WILLIAM H. DALL AND JOSEPH STANLEY-BROWN

This paper is printed as pages 147–170 of this volume.

A recess was then taken until 2 o'clock p m.

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* Fl. Foss. Arct., vol. vi, 1 Abth., 3d nr.; Beiträge zur Miocene Fl. v. Nord-Canada.

† *Ibid*, vol. vi, 1 Abth., 4th nr.; Untersuchung ü. foss. Hölzer d. Arct. zone.

‡ Trans. Roy. Soc. Canada, 1889; Fossil Plants from Mackenzie and Bow Rivers.

On reassembling, the following paper was read, Vice-President Chamberlin presiding:

*GEOLOGIC ACTIVITY OF THE EARTH'S ORIGINALLY ABSORBED GASES*

BY ALFRED C. LANE

Remarks were made by H. F. Reid. The paper is printed at pages 259–280 of this volume.

Announcements were made by Professor Niles relating to the proposed dinner Thursday night; also by Professor Davis and the Secretary in reference to the program of Thursday.

The President resumed the chair and the following paper was read:

*DUAL NOMENCLATURE IN GEOLOGIC CLASSIFICATION*

BY H. S. WILLIAMS

Remarks were made by Alpheus Hyatt and the President. The paper is published in The Journal of Geology, volume 2, page 145, and abstracts in The American Geologist, volume xiii, page 139, and The American Journal of Science, volume xlvii, page 143.

The following paper was read by the author:

*JOHANN DAVID SCHOEPF AND HIS CONTRIBUTIONS TO NORTH AMERICAN GEOLOGY*

BY GEORGE HUNTINGTON WILLIAMS*

It may be a matter of some satisfaction to American geologists to know that an excellent, but now almost forgotten work on the geology and mineralogy of the eastern United States south of New York was published at the time when the names of Werner and Hutton were just beginning to be heard in the scientific circles of Europe. Its author, a young German whom the accident of war brought to our shores, was as well equipped as any of his contemporaries for the scientific appreciation of the natural phenomena of a new country. Although a graduate in medicine, as was usual a century ago for all students of natural history, he had both interest and training in mineralogy, mining, geology, physical geography and meteorology, zoölogy and botany. To these were coupled a strong desire for travel, a keen power of observation and a facility in accurately describing what he saw. Such gifts did not need any great originality or power of generalization to insure for him an honorable position at home or the recognition by his contemporaries of the many works on America, to which he devoted the last fifteen years of his short life. They were not, however, enough to prevent his contributions from sinking

* The writer's attention was first called to the work of this interesting man by Dr John M. Clarke of the State Museum at Albany.

into oblivion amidst the restless scientific energy of the succeeding century. For more than fifty years America was far behind Europe in scientific spirit and discovery, and it is now worth remembering that many of the localities which we are now busy in investigating were appreciated and described before either the Master of Freiberg or the Founder of Uniformitarianism had begun to make their influence felt.

The man to whom we owe this early contribution to our eastern geology was Johann David Schoepf, the son of a well-to-do merchant of Wunsiedel in the Fichtelgebirge. He was born March 8, 1752 and left the gymnasium at Hof at the age of eighteen to pursue the study of medicine, mineralogy and mining at the University of Erlangen. Here the influence of Hofrath Schreber, who first introduced the results of Linnæus into Germany, awakened in him an equal interest in botany and zoölogy. His father's means enabled the young man to satisfy his longing for travel, and before taking his doctor's degree at Erlangen in 1776, he had visited Berlin and made an extensive tour through Bohemia, Austria, Italy and Switzerland. After finishing his studies Schoepf decided on a voyage to India, but his activity was turned into another channel by an offer of a position as surgeon to one of the Bavarian regiments hired by England to suppress the rebellious colonies in America. In this capacity he reached New York June 4, 1777, where he remained with no chance to explore the surrounding country until the close of the war. After the return of the German mercenaries in 1783, Schoepf devoted a year to travel and to the collection of material which, with what he had gathered during the six years of his service as surgeon, was sufficient to occupy his attention until his death in 1800. He visited New Jersey, Philadelphia, the German settlements near Bethlehem and the remoter parts of Pennsylvania. He also crossed into Maryland and stopped at Baltimore, Annapolis and Wilmington before his return to Philadelphia in October, 1783. The following month he entered upon a still more extensive journey through Virginia, the Carolinas and Florida. He spent January 1784 in Charleston and some weeks at Saint Johns and Saint Augustine. Thence he crossed to the Bahamas and arrived in London July 30, 1784. England and France were then slowly traversed and Bayreuth reached the following October.

Although his quiet was interrupted by an occasional journey, Schoepf devoted most of his remaining years to the elaboration and publication of his scientific data relative to eastern North America.

His interests were broad and his material was varied and new. He wrote on medicine, climatology, zoölogy, mineralogy and geology, besides interesting descriptions of manners, life and politics in the newly established states. His work on the Climate and Diseases of North America was translated by James Reed Chadwick.* His most elaborate work appeared in Latin as the "*Historia Testudinum*," with many beautiful colored plates, and remained unfinished at the time of his death. The fishes, frogs and jellyfishes of American waters were also made the subjects of separate memoirs. His best known work is his "*Reise durch einige der mittlern und südlichen vereinigten Nordamerikanischen Staaten, nach Ost Florida und den Bahama Inseln*," in two volumes, 1788. In this he discusses climate, sea currents, sea fauna and many questions of a social and political character, especially the planter barons of the south and their relation to slavery. He was perhaps the first to clearly formulate Dove's law of the winds. He also tells many good stories and incidents which graphically portray the general status of the remoter parts of the country and the difficulties of travel in these times.

* Boston, 1825.

The work of Schoepf which is of the most interest to geologists is the "*Beyträge zur Mineralogischen Kenntniss des östlichen Theils von Nordamerika und senier Gebürge.*"* Descriptions of eastern North America, containing more or less reference to its geology and physical geography, had before been published by M. Catesby,† Steph. Guettard,‡ Lewis Evans,§ and Peter Kalm,‖ but none of these equal for exactness or scientific spirit the work of Schoepf. In his dedication of it to Hofrath Schreber he says: "As I left Europe in 1777 you gave me the commission 'to investigate the arrangement of soil and rock beds in America and to discover to what extent the sequence established by von Ohain and Ferber for Europe held good also for the New World.'" These, for that time, remarkably clear instructions were conscientiously carried out, and the results communicated in the "*Beyträge.*" He says that he explored the Appalachian mountain region only between the Hudson and Potomac, but that he carefully traversed the coastal region, including the crystalline rocks of the Piedmont plateau, by land from Rhode Island to Florida.

The little book contains 194 pages, divided into 47 numbered sections. The first thirteen sections (pages 1–34) deal with the Coastal Plain deposits, and the following twelve (pages 34–77) with the highly crystalline or granitic belt forming the eastern part of the Piedmont plateau. In this the Baltimore gabbros are quite correctly described. Between the granitic belt, which he calls "*der Erste Felsreihe,*" and the mountains proper, Schoepf correctly distinguishes three limestone and two crystalline belts, which, for the latitude of Maryland, he describes with admirable clearness. These are: "*Erste Kalchlage*" (the marble belt); "*Zweite Felsreihe*" (the western Piedmont semi-crystalline zone); "*Zweite Kalchlage*" (the Frederick valley limestone); "*dritte Felsreihe*" (South mountain or the Blue ridge); and "*dritte Kalchlage*" (the Great or Cumberland valley). Sections 32 to 37, inclusive (pages 105–143), are devoted to the mountains proper (*Hauptgebürge*), with a special description of the Kittatinny and accounts of two sections carefully traversed from the Kittatinny to the Susquehanna at Wyoming and from Shippensburg to Pittsburg.

To these descriptive portions succeed discussions of the drainage and soils; of the fossils in the mountains and their significance; of the origin of wind and water gaps, and of the comparative newness of the Coastal Plain deposits, with proofs of the sinking of the area east of the granitic zone. Many of the conclusions here set forth are in the main those now generally accepted, and bear witness to the acumen of their author.

A few pages are added on the country north and west of the mountains in Canada and New England, but as what they contain was derived from hearsay and not from personal observation they are of little importance.

Sources of information regarding Schoepf and his work are—

Fikenscher: *Das gelehrte Fürstenthum*, Bayreuth, 1795.

Mensel: *Lexikon der vom Jahre, 1750 bis 1800, verstorbenen Teutschen Schriftsteller*, vol. 12, 1812, p. 364, with complete bibliography.

G. Brown Goode: *Beginnings of Natural History in America.* Proc. Biol. Soc. Wash., vol. iii, 1886, p. 92.

Fr. Ratzel: Biographical Notice in the *Allgemeine Deutsche Biographie*, vol. 32, 1891, p. 352.

* Erlangen, 1787, pp. 194.

† Natural History of Carolina, Florida, and Bahama Islands, 1731.

‡ Mémoire dans laquelle on compare le Canada et la Suisse par rapport à ses mineraux, 1752.

§ Analysis of a general map of the Middle British Colonies, 1756.

‖ En Resa til Norra Amerika, 1753–'61, 3 vols. English translation by J. R. Forster, 1770–'71.

The following paper was read by title:

### *RELATIONS OF SYNCLINES OF DEPOSITION TO ANCIENT SHORELINES*

BY BAILEY WILLIS

An abstract of this paper is published in The American Geologist, volume xiii, February, 1894, page 140.

The next communication was:

### *THE LATER TERTIARY LACUSTRINE FORMATIONS OF THE WEST*

BY W. B. SCOTT

[*Abstract*]

The uppermost of these horizons in the western interior region has been called the *Equus* beds, which in many places overly the Loup Fork beds and have not always been distinguished from them with sufficient accuracy. Hatcher has shown, however, that the two are separated by a marked unconformity, and there are notable lithologic differences also. The mammalian fauna of the *Equus* beds, while abundant in individuals, is scanty in species, which, for the most part, belong to modern genera, such as *Equus*, *Elephas*, etcetera, together with a few extinct genera, as, for example, *Mylodon*, *Eschatius*, etcetera. Rhinoceroses, which are so conspicuously represented throughout the undoubted Tertiaries of North America, have not been found in the *Equus* beds, except, perhaps, in California, where they appear to have lingered later than elsewhere. The character of this fauna points rather to a Pleistocene than a Pliocene age of the beds.

The Blanco of Texas, described by Cope, is a typical Pliocene, the only beds so far identified in the West of which such an age can be certainly predicated. They precede somewhat the Peace Creek beds in Florida, which Dall has found interstratified between marine Pliocene beds.

The great Loup Fork formation has been much misunderstood, partly because it has not always been distinguished from the much later *Equus* beds, and partly because the separate horizons into which it may be divided have but lately been worked out. Of these there are three. The oldest is the Deep River horizon of Montana (*Ticholeptus* bed of Cope) and is characterized especially by a number of aberrant oreodonts and some peculiar genera of horses, such as *Desmatippus* and *Anchitherium*. This horizon is so far known only in Montana. I cannot agree with Cope in referring to it certain deposits in Wyoming and Oregon.

The second or middle horizon of the Loup Fork covers a vast area from Nebraska to Mexico, and has yielded a very large number of mammals. Of these the most characteristic is, perhaps, the antelope-like genus *Cosoryx*. An appropriate geographic name for this subdivision would be the Nebraska.

The latest of the three horizons of the Loup Fork may be called the Palo Duro, Cope having found it near the canyon of that name in Texas, and Hatcher has observed it in northern Kansas overlying the Nebraska series. The horizon is characterized by the first appearance of the genera *Equus* and *Hippidium*, while *Protohippus* and *Aphelops* continue up from the Nebraska or Loup Fork proper.

The mammalian fauna which has been found at and near Archer, in Florida,

corresponds very closely with that of the Palo Duro horizon, and represents a formation nearly or quite contemporaneous with it. These Archer fossils have sometimes been regarded as the equivalents of those in the Peace Creek beds, but they are much older and represent a very different fauna.

The two older Loup Fork horizons, the Deep River and Nebraska, belong unquestionably to the Miocene, the reference of them to the Pliocene, which has been made by some authorities, is due partly to incorrect identifications of fragmentary fossils and partly to a mingling of fossils from different horizons, such as very frequently occurs in localities where the *Equus* beds overlie the Loup Fork. For stratigraphic reasons Dall regards the Archer deposits as Pliocene: and if this contention proves to be well founded the line between Miocene and Pliocene should be drawn between the Nebraska and Palo Duro horizons of the Loup Fork. The following table will display these relations:

| | | | |
|---|---|---|---|
| Pleistocene | *Equus* beds. | | |
| Pliocene | Peace creek.<br>Blanco. | | |
| Upper Miocene | Loup Fork | Palo Duro and Archer | = *Hippidium* beds. |
| | | Nebraska | = *Cosoryx* beds. |
| | | Deep river | = *Cyclopidius* beds. |

A much more difficult task is to correlate these various horizons with their equivalents in Europe. Many of our leading geologists deprecate all such attempts in the present state of knowledge, and from the stratigraphic point of view this is very natural. From the standpoint, however, of morphologic paleontology, which deals with questions of origins and migrations, correlations are simply indispensable and must be attempted again and again until a satisfactory result has been reached. A false correlation will sooner or later refute itself by the contradictions and absurdities to which it leads, as is abundantly shown by the inferences which follow from regarding the White River deposits as Miocene rather than Oligocene. For the purpose of correlating the lacustrine deposits of Europe and North America, the principal stress must be laid upon the mammals, and from the comparative rapidity of change which this group displays nothing could be better adapted to the purpose, provided the proper limitations of this method be observed. The comparison of mammalian faunas in widely separated and isolated regions can lead to no satisfactory result, and it is this which renders the determination of the South American fresh-water Tertiaries so very difficult. Throughout Tertiary time South America was isolated from the northern continents and developed a fauna entirely peculiar to itself. The effects of this long isolation are strongly marked, even at the present time. On the other hand, North America was repeatedly and for long periods connected with the Old World, and frequent migrations of mammals occurred in both directions. During periods when this connection appears to have been interrupted very peculiar faunas developed on this continent in isolation, a striking example of which is the Bridger Eocene, but then subsequent removal of barriers reëstablished similarity.

Time forbids entering into these correlations in detail. Here it will suffice to indicate three points which appear to be well fixed as equivalents on the two sides of the ocean:

1. The Wasatch Eocene represents the Suessonian of France (Cope).
2. The White River beds are the equivalent of the Oligocene of Ronzon.
3. The Deep River horizon of the Loup Fork corresponds to the Upper Miocene of Sansan.

Professor Scott's paper was discussed by G. K. Gilbert and E. T. Dumble, after which the Society adjourned until evening.

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### Session of Wednesday Evening, December 27

The Society was called to order at 7.45 p m, President Dawson in the chair. The following paper, which was announced for this session in the printed program, was presented with illustrations:

*AN ACCOUNT OF AN EXPEDITION TO THE BAHAMAS*

BY ALEXANDER AGASSIZ

Remarks were made by the President.

A second paper was read—

*THE SHASTA-CHICO SERIES*

BY J. S. DILLER

This paper was combined with the one by T. W. Stanton, entitled The Cretaceous Faunas of the Shasta-Chico Series, and printed under their joint authorship as pages 435–464 of this volume.

Following the early adjournment, an informal reception was given in the library room of the building.

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### Session of Thursday, December 28

The session of this day was held in the University Museum of Harvard University, Cambridge. The Society was called to order in the Nash Botanical Lecture-room, and was welcomed by Professor N. S. Shaler. Vice-President Chamberlin presided during the day.

The first paper read was:

*GEOLOGY OF A PORTION OF THE COOSA VALLEY IN GEORGIA AND ALABAMA*

BY C. WILLARD HAYES

Remarks were made by N. S. Shaler. This paper is printed as pages 465–480 of this volume.

The second paper was:

*PALEOZOIC OVERLAPS IN MONTGOMERY AND PULASKI COUNTIES, VIRGINIA*

BY M. R. CAMPBELL

This paper is printed as pages 171–190 of this volume.

The following paper was read:

*GEOLOGIC RELATIONS FROM GREEN POND, NEW JERSEY, TO SKUNNEMUNK MOUNTAIN, NEW YORK*

BY N. H. DARTON

Remarks were made by J. E. Wolff. This paper is printed as pages 367–394 of this volume.

The next paper presented was:

*ANCIENT ERUPTIVE ROCKS IN THE WHITE MOUNTAINS*

BY C. H. HITCHCOCK

The paper was discussed by J. P. Iddings and N. S. Shaler. An abstract is published in The American Geologist, volume xiii, March, 1894, page 213.

The following paper was then read:

*ANCIENT VOLCANIC ROCKS ALONG THE EASTERN BORDER OF NORTH AMERICA*

BY GEORGE H. WILLIAMS

This paper was discussed at length by A. C. Lane, J. P. Iddings, Whitman Cross, J. S. Diller and the author. It is published in full in The Journal of Geology, volume ii, 1894, pp. 1–34.

The following paper was read by the author, but not presented for publication:

*THE CHEMICAL EQUIVALENCE OF CRYSTALLINE AND SEDIMENTARY ROCKS*

BY G. K. GILBERT

In the absence of the author the next paper was read by George H. Williams.

## VOLCANITE, AN ANORTHOCLASE-AUGITE ROCK CHEMICALLY LIKE THE DACITES

BY WILLIAM H. HOBBS*

[*Abstract*]

The eruption of Volcano † in 1888-'9 produced a peculiar type of volcanic projectile which Dr H. J. Johnston-Lavis has characterized by the term, "bread-crust bomb." ‡ These projectiles consist of an acid pumice core surrounded by a thin skin of a vesicular glassy rock, which is warped and cracked by reason of the strains to which it has been subjected in cooling. The structure of the projectiles § has been discussed in the papers cited.

The material of the bombs is porphyritic in structure with a glassy base, phenocrysts of felspar and augite being prominent in both core and rim. They are often quite large, the felspars attaining a diameter of three-quarters of a centimeter. Inclusions of a more basic rock occur which are, with little doubt, fragments of the dolerite so extensively developed at the south end of the island. An acid enclosure obtained by Professor J. P. Iddings in a subsequent visit to the island was found on examination to be quite certainly a partially fused fragment of liparite. Dark colored inclusions having the outline of crystals, which are quite abundant in the rock, have been shown to be magmatic pseudomorphs after augite phenocrysts.

The predominating felspar of the phenocrysts resembles sanidine, and generally appears under the microscope as idiomorphic unstriated individuals, bounded by the faces *P*, *M*, *l* and *y*. Cleavage pieces parallel to the base extinguish parallel, and those parallel to the second cleavage yield an extinction angle of from 4 to 7 degrees. An obtuse positive bisectrix emerges from the latter. In most cases there is no trace of twinning striæ, but rarely an extremely fine microcline-like striation can be made out in the section. Simple twins, according to the Baveno law, were observed. Parallel and knotty or "knaüelformig" growths of felspar are very common. A fragment of the unstriated felspar free from inclusions was found to have a specific gravity of 2.559. A sufficient quantity of this felspar was separated from the rock, with a slight admixture of magnetite and augite, by means of the Thoulet solution. As these impurities do not compose entire grains of the rock powder used in the separation, they were not easily removed. An analysis of this material by W. F. Scoular is given under I in the following table:

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* I desire to acknowledge obligation to Messrs Louis Kahlenberg, Leo C. Urban, and M. F. Scoular for the chemical analyses furnished by them for this paper, and I am also indebted to Professor George H. Williams, of Johns Hopkins University, for valuable suggestions.

† Volcano is situated on one of the Lipari islands.

‡ Johnston-Lavis: Proc. Geol. Assoc. London, vol. xi, 1890, p. 390. Also Nature, vol. xlii, 1890, p. 78. Hobbs: Trans. Wis. Acad., vol. ix, 1893, p. 21, pl. 1, fig. 2.

§ The present pa er is an abstract of a study of the material of the projectiles from a petrographical standpoint. The full paper will appear in the Zeit-chrift der deutschen geologischen Gesellschaft.

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| $SiO_2$ | 60.01 | 58.18 | 64.59 | 62.27 | 47.60 |
| $Al_2O_3$ | 20.12 | 22.89 | 19.84 | 21.07 | 4.66 |
| $Fe_2O_3$ | 2.82* | 4.58 | 2.24 | ........ | ........ |
| FeO | ........ | ........ | ........ | ........ | 12.73 |
| CaO | 5.15 | 4.61 | 1.26 | 5.10 | 18.06 |
| MgO | .23 | .71 | .63 | ........ | 14.56 |
| $K_2O$ | 3.67 | 4.17 | 3.53 | 3.86 | ........ |
| $Na_2O$ | 6.43 | 2.97 | 7.88 | 6.76 | 1.50 |
| MnO | ........ | ........ | ........ | ........ | trace. |
| $H_2O$ | .77 | .96 | ........ | .81 | .50 |
| | 99.20 | 99.07 | 99.97 | ........ | 99.61 |
| Specific gravity | 2.559 | ........ | ........ | ........ | 3.283 |

I. Anorthoclase from Volcano projectiles of 1888; analyzed by W. F. Scoular.

II. Anorthoclase from the "Rhombenporphyr" of Lille Frogner; analyzed by Kjerulf.†

III. Anorthoclase from the taimyrite of the Taimyr river, Siberia.‡

IV. Same as I, recalculated so as to exclude magnetite and augite impurities.

V. Augite from Volcano projectiles of 1888; analyzed by L. C. Urban.

The analysis of this felspar clearly shows that it is sodium orthoclase, the composition corresponding to $Or_1\ Ab_{2.55}\ An_{1.12}$. The study of the sections indicates that we have present both the "Natronorthoklas" and the "Natronmikroklin" of Brögger.

The plagioclase of the phenocrysts has a more lath-shaped habit and shows the albite striation. The extinction angles in the zone of the ortho-diagonal indicate that the felspar is near the middle of the plagioclase series. A portion was separated in the Thoulet solution and partially analyzed for me by Mr Leo C. Urban with the following results:

CaO...... 6.47  $Na_2O$...... 5.22  $K_2O$...... 1.87.

The potash present is probably explained by the fact that the anorthoclase was not quite eliminated from the portion analyzed. If correction be made for this the mineral is seen to be an andesine of the formula $Ab_1\ An_1$. Besides the large phenocrysts, both anorthoclase and andesine occur in a second generation of phenocrysts as well as in the groundmass, so that three distinct generations are recognized.

Augite, like felspar, occurs in three generations. The phenocrysts show about equal development of pinacoids and prism. Both pinacoidal partings are generally more or less developed, and twins, according to the usual law, are common in the phenocrysts of the second generation. Fluid inclusions filling cavities of the form of negative crystals are very common. The absorption is green in tones from yellowish green to deep green or deep brownish green, indicating the presence of a

* Total iron.

† W. C. Brögger: Die Silurischen Etagen, p. 295.

‡ See K. v. Kroutschoff: Bull. acad. im. St. Petersburg, Mélang. géol. et paléon', I, liv. 1.

perceptible quantity of the acmite molecule. The extinction angles in the prism zone are as high as 40°. Marked zonal structure is characteristic of many crystals representing a difference in extinction angle sometimes as great as 8°. An analysis of this mineral is printed under V in the preceding table. The one and a half per cent of sodium present explains the yellowish green absorption of the mineral. The extensive resorption which has occurred in the case of many individuals is of considerable interest. This does not seem to have taken place with any uniformity about the crystal, but has frequently made its way to the center of the crystal from one side, even when the greater part of the surface remains unattacked. The material thus dissolved has again crystallized in place as an aggregate of nearly colorless pyroxene, magnetite and plagioclase. Such resorption has frequently gone so far as to produce perfect magmatic pseudomorphs after the augite phenocrysts. In the examination of the hand specimen these can be seen as dark colored areas with good crystal boundaries, having the appearance of basic inclusions. Under the microscope the outlines are easily identified as those of augite, since octagonal basal sections are found having the pyroxene angle. Moreover, remnants of the original augite crystals, which are sometimes found in these pseudomorphs, indicate by their orientation and cleavage that they once filled the entire space of the inclusion. The pseudomorphs are easily distinguished from the host by the large amount of magnetite, the needles of colorless pyroxene, and the base of plagioclase of which they are composed. The pyroxene of the normal rock is, as already mentioned, green, and in the groundmass it plays quite a subordinate rôle. Unlike the rock groundmass, the pseudomorphs contain no vesicles and no glassy base. They must be explained in the same manner as are the magnetite-augite crowns about biotite and hornblende in the andesites. While the lava stood in the pipe of the volcano a differentiation of the magma occurred, which rendered the already formed augite phenocrysts unstable. Their resorption began in consequence, and owing to the great viscosity of the lava the diffusion of the resorbed material was practically *nil.* As a consequence the material recrystallized *in situ*, but on account of the changed conditions, in other chemical molecules. These augite pseudocrystals show analogies with the leucite pseudocrystals, which have been described from Arkansas* and Brazil.†

A mineral which was occasionally observed in the rock, having a high index of refraction, a high double refraction, and a rough surface, was identified as olivine, though its presence was hardly to be expected.

The groundmass of the rock has a glassy base, in which are contained a great number of microlites of felspar and a much smaller number of small augite crystals. It contains occasional larger or smaller irregular shaped inclusions, which appear to be partially fused fragments of dolerite. A rare white inclusion which was found later by Iddings on his visit to the island and kindly given me to examine is undoubtedly a metamorphosed liparite. It is composed chiefly of felspar and quartz. Cleavage pieces of the felspar show the optical characters of "normal" sanidine. A partial analysis of the inclusion has been made for me by Mr Leo C. Urban with the following results:

$SiO_2$...... 74.57. $Al_2O_3$...... 13.09. CaO...... 1.32.

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* J. F. Williams: The Igneous Rocks of Arkansas. Ann. Rept. Geol. Surv. Ark., 1890, vol. ii, p. 267.
† Eugen Hussak: Neues Jahrb., 1892, vol. ii, p. 159.

These figures correspond almost perfectly with percentages of the same oxides in the analyses of obsidian and pumice from Lipari.* It is interesting in this connection to note that Abich † has described a liparite from within the crater of Volcano which contained 70.50 per cent of silica.

Mineralogically, then, this rock resembles most the trachytes, but as anorthoclase takes the place of sanidine, it should, therefore, be classed with the pantellerites. The phenocrysts are in two generations, and are anorthoclase, andesine, acmitic augite and olivine. The only accessory minerals are magnetite and microlitic apatite needles. The Michel-Lévy formula for this rock would then be:

$$\pi\mu - \overline{(F\,1.5)\,\underline{\underline{(OP_4)\,a_2}}t_1}.$$

A small fragment of the outer rim of a projectile as free from vesicles as any that could be found was determined to have a specific gravity of 2.42.

Some fragments of both the pumiceous core and the glassy rim of a projectile were taken and, after picking out the doleritic inclusions, subjected to a complete chemical analysis. The results of this analysis, which was kindly made for me by Mr Louis Kahlenberg, instructor in chemistry in the University of Wisconsin, are printed under I in the following table. In columns II to VI are printed other rock analyses for comparison.

| | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| $SiO_2$ | 66.99 | 66.41 | 67.19 | 66.3 | 63.2 | 69.0 |
| $Al_2O_3$ | 17.56 | 17.41 | 16.96 | 17.8 | 16.3 | 10.1 |
| $Fe_2O_3$ | 1.41 | 4.12 | 3.45 | 2.4 | 1.8 | 4.4 |
| FeO | 3.39 | ........ | 1.20 | .4 | 2.4 | 4.6 |
| MnO | trace | ........ | trace | ........ | ........ | ........ |
| CaO | 4.25 | 3.96 | 4.46 | 2.1 | 3.6 | 1.5 |
| MgO | .93 | 1.82 | 1.50 | .3 | 1.9 | .8 |
| $Na_2O$ | 3.35 | 3.83 | 3.70 | 5.6 | 2.5 | 6.3 |
| $K_2O$ | .34 | 1.65 | 1.55 | 3.5 | 6.0 | 3.7 |
| $H_2O$ | 1.53 | .81 | .89 | .2 | 2.3 | ........ |
| $P_2O_5$ | trace | ........ | ........ | ........ | ........ | ........ |
| Others | ........ | ........ | ........ | 1.3 | 1.0 | .3 |
| | 99.75 | 100.01 | 100.88 | 99.9 | 101.0 | 100.7 |

I. Total analysis of the Volcano projectiles of 1888.
II. Felso-dacite from Rodua, Siebenbürgen. ‡
III. Dacite from Nagy Sebes, Siebenbürgen. §
IV. Domite from the Puy de Dôm, Auvergne.
V. Trachyte from Monte Amiata. ||
VI. Pantellerite from Cuddia Mida, Pantelleria. ¶

* J. Roth: Die Gesteinsanalysen, p. 11.

† Abich: Vulkanische Erscheinungen, 1841, p. 26.

‡ Doelter: Tscherm. min. Mitth., vol. iii, 1873, p. 74.

§ Cf. Ibid., p. 93. This rock is the type of dacite cited by Rosenbusch (Ueber die chemischen Beziehungen der Eruptivgesteine, ibid., N. F., vol xi, 1890, p. 178).

|| J. F. Williams: Inaugural Dissertation, Stuttgart, 1887, p. 33.

¶ Förstner: Zeitsch. f. Kryst., vol. viii, 1883, p. 182.

That the rock of the Volcano projectiles does not belong in the trachyte series but is chemically like the dacites, is clear from the above analyses. Analyses II and III are of typical dacites, with which this rock is chemically almost identical. The domite of the Auvergne (IV) and the Monte Amiata trachyte (V) contain much more potash. The pantellerites contain more potash and iron and much less alumina and lime. The other trachyte types show chemically even less affinity with the rock under consideration.

Although the rock under consideration is chemically identical with the dacites, it lacks the characteristic quartz phenocrysts of that type. Further, the study of the sections shows that this rock belongs, mineralogically, in the trachyte series with the pantellerites. Anorthoclase is the predominating felspar and monoclinic pyroxene, which is the rarest non-felspathic essential constituent of the dacites, is here beside felspar the only essential constituent of the rock. This rock does not therefore correspond with any of the established rock types. Mineralogically it is a trachyte, while chemically it is a dacite. I propose for this new type the name Volcanite after the crater from which it has been ejected—Vol, cano—the most symmetrical and beautiful of all cinder cones.

Professor J. P. Iddings has demonstrated that one and the same rock magma may under different conditions consolidate in different mineral aggregates.* The rock type which arises in a given case depends on the manner of geological occurrence and on the physical conditions attending the consolidation. These latter may be the pressure, the temperature, the rate of radiation, the mineralizers present, etcetera. In the type before us the development of anorthoclase and monoclinic pyroxene, and not quartz, acid plagioclase, and biotite or hornblende, as is usual with magmas of this chemical composition, may in part be due to the peculiar manner of formation of the "bread-crust" projectiles.

The following paper was read by title:

## *FURTHER NOTES ON THE OCCURRENCE OF ALBERTITE IN NEW BRUNSWICK, CANADA*

BY H. P. H. BRUMELL

The Society took a recess for luncheon, which was served in the building by the resident Fellows, and reconvened in the Geological Lecture-room at 1.30 p m. The first paper presented at the afternoon session was—

## *ALTERATIONS OF SILICATES IN GNEISS AT WORCESTER, MASSACHUSETTS*

BY HOMER T. FULLER

* J. P. Iddings: The mineral composition and geological occurrence of certain igneous rocks. Bull. Phil. Soc. Washington, 1889, vol. xi, pp. 191–220. Also Iddings: On the crystallization of igneous rocks, ibid., p. 90; and, The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park, 12th Ann. Rep. Director U. S. Geol. Survey, 1892, pp. 569–664.

The next paper was read, in the absence of the author, by J. P. Iddings:

*PRE-PALEOZOIC DECAY OF CRYSTALLINE ROCKS NORTH OF LAKE HURON*

BY ROBERT BELL

This paper is printed as pages 357–366 of this volume.

The following communication was presented:

*GABBROS ON THE WESTERN SHORE OF LAKE CHAMPLAIN*

BY J. F. KEMP

This subject was discussed by G. H. Williams, F. D. Adams, and the author replied. The paper is printed as pages 213–224 of this volume.

The next paper was read by title:

*MICA DEPOSITS IN THE LAURENTIAN OF THE OTTAWA DISTRICT*

BY ROBERT W. ELLS

The paper is printed as pages 481–488 of this volume.

The next paper was—

*INTRUSIVE SANDSTONE DIKES IN GRANITE*

BY WHITMAN CROSS

Remarks upon this paper were made by N. S. Shaler. The paper is printed as pages 225–230 of this volume.

The following paper was read by title:

*AGE OF THE AURIFEROUS SLATES OF THE SIERRA NEVADA*

BY JAMES PERRIN SMITH

The paper is printed as pages 243–258 of this volume.

The following paper was read, in the absence of the author, by W. M. Davis.

*CERTAIN CLIMATIC FEATURES OF MARYLAND*

BY WILLIAM B. CLARK

The substance of this paper is published in the First Biennial Report of the Maryland State Weather Service for the years 1892 and 1893.

The next paper was read by title:

*GEOLOGICAL STRUCTURE OF THE HOUSATONIC VALLEY LYING EAST OF MOUNT WASHINGTON*

BY WILLIAM H. HOBBS

This paper is published in The Journal of Geology, volume 1, 1893, page 780.

The following paper was illustrated by lantern views:

*THE HIBERNIA FOLD, NEW JERSEY*

BY J. E. WOLFF

An abstract is published in The American Geologist, volume xiii, page 142.

The following three papers were presented by the author:

*PLEISTOCENE DISTORTIONS OF THE ATLANTIC SEACOAST*

*RELATION OF MOUNTAIN-GROWTH TO FORMATION OF CONTINENTS*

*PHENOMENA OF BEACH AND DUNE-SANDS*

BY N. S. SHALER

These papers are printed as pages 199–212 of this volume.

The following communication was read:

*THE TRIAS AND JURA IN THE WESTERN STATES*

BY ALPHEUS HYATT

The paper was discussed by J. S. Diller, Mr Alexander Agassiz and the author. It is printed as pages 395–434 of this volume.

The following paper was read by title:

*GEOGRAPHICAL WORK FOR STATE GEOLOGICAL SURVEYS*

BY WILLIAM M. DAVIS

Our state geological surveys, which should be organized in every state as permanent official bureaus with an assured future, have at present too commonly an uncertain existence; so uncertain that a graduate of our colleges might well question the advisability of casting his lot in a service on whose permanence so little dependence can be placed. There are two chief reasons for this unfortunate condition of things. The first is the little interest felt by the average state legislator in

matters that have not an immediate practical application; the second is the relatively small appreciation of the survey reports by the greater part of our population.

On the other hand, the subject of geography is in a lamentable condition in our public schools, and is most seriously in need of an infusion of new life. There are many reasons for this, but one of the chief is the want of good literature ready at hand for the teacher's use. A teacher in the public schools, anxious to improve his work by introducing illustrations and examples from his home field, may search almost in vain for descriptions of the geographical features of his state, presented at once in the light of modern geographical investigation and in a style adapted to his needs.

In view of these two unsatisfactory conditions, I venture to ask the attention of our Fellows, especially of those who are engaged in state surveys, to the following outline of a plan by which some improvement may be effected, both in the surveys and in the schools:

Physical geography, which treats chiefly of the forms of the land produced by denudation, is now universally recognized as a division of the larger subject of geology, which includes also an account of the formation of land masses by processes of deposition and deformation. Hence in those state surveys which are not strictly limited by law to the consideration of the economic occurrence of ores, building stones, clays, etcetera, let there be a geographical division established, in which one or more competent geographical assistants shall be employed to investigate and report on the geographical features of the state, just as trained economic experts, paleontologists or petrographers are employed to examine the appropriate subjects of their studies.

Let the geographical assistant be instructed to study and report upon a certain limited group of geographical features; let him traverse his district until all its parts are familiar, determine as clearly as possible the conditions of their development and illustrate their several parts by photographs, sketches, maps, and so on; let him while yet on the ground begin his report, in order that it shall approach completion while the features that he describes are still before him; then let his "office work" be devoted to broadening his report by a comparison of the local features with others of similar origin in other parts of the country or in other countries of the world, and by contrast with related features of earlier and later stages of development, or in fainter or stronger intensity of relief, or under different climatic conditions. Just as with reports on ores, rocks or fossils, let the geographical report be prepared in accordance with a systematic scheme based on a study of the geography of the world. Just as with the reports on other subjects, let the geographical reports represent the best developments of modern geographical investigation. Just as with the reports on other subjects, let the geographical reports be carefully prepared to meet the requirements of the part of the community to which they are addressed.

In this last respect the geographical reports need a most careful consideration. They should be addressed to the teacher in our high schools, because it is from among the graduates of the high schools that the teachers of the grammar schools are drawn. Teachers of grammar-school grade also are indeed at present greatly in need of a good local geographical literature to which they can refer for illustration of their text-book lessons, and many of them will make good use of such literature; but the best use that they can make of it will be gained if they meet it while they are still scholars themselves—that is, in their high-school course—so that it shall

be closely woven into their geographical training. While the effect on the high schools might therefore be almost immediate, the effect on the grammar schools can hardly be expected until a decade shall have passed.

A geographical report ready for successful use as a reference book by a high-school teacher of physical geography must not be too technical; it must not presume too much on antecedent knowledge of the modern aspects of physical geography; it must dwell deliberately on a simple series of related considerations; it must illustrate them verbally and graphically; it must detain the reader's interested attention by a selected sequence of comparisons and contrasts; it must bring out clearly the marked relation between physical features on the one hand and seats of population, styles of occupation and paths of communication on the other hand; it must touch close to matters of historical and economic interest.

Let no geologist, far removed by his difficult investigations from the simpler studies of the high school, imagine that such reports as are indicated above are trivial matters. Let him rather feel assured that they open a field for originality of treatment that will place their successful authors prominently before the educational public. It is quite true that the order of considerations that they involve is relatively elementary; but it is, on the other hand, nothing less than astonishing to discover how many facts of the highest geographical interest are both elementary and unknown. They may, indeed, be known to a few persons who live upon them, or to a few investigators who have encountered them in the field, but they are nowhere properly presented in accessible books, ready at hand for use in our schools. As a result, our high-school graduates—that is, the great body of our more intelligent population—live in a world whose expressive features they do not in the least understand.

Let me illustrate briefly, by a few specific examples, the general quality of the subjects for geographical reports of the kind which I have in mind.

Consider, for example, the more or less distinct inland-facing escarpments that run in a rough way parallel to the seashore in our great coastal plain. On their inland side lies a valley-lowland, developed by the denudation of the weaker strata that have been exposed by the removal of the harder members of the retreating escarpment. According to the strength of the escarpment and to certain other features, the drainage of this interior longitudinal valley-lowland will be effected by a less or greater number of transverse streams which maintain open waterways through the escarpment. While the face of the escarpment looks upon a valley-lowland opened on older strata, the back of the escarpment descends to a lowland-plain, or to another valley-lowland enclosed by another escarpment. According to the constitution of the strata and to the conditions of relief, climate, etcetera, the inner lowland, the outer lowland and the intermediate escarpment will vary in products, population, occupations and so on. According to the attitude of the strata, the escarpment may be ragged, faint and ill-defined, or straight, strong and sharp. Although the drainage systems of regions of this kind usually present interesting examples of mature adjustment between consequent and subsequent streams, the processes involved in the adjustments are sufficiently simple for presentation to high school teachers, and for use by them in the better illustration of the texts that their scholars follow. Innumerable examples of escarpments in other countries might be introduced in illustration of various styles and stages of development. There is the double escarpment of the oölite and the chalk, by which England is divided into a formerly wealthier agricultural community on the

southeast, and a now wealthier mining and manufacturing community on the northwest. There are the encircling escarpments by which the Paris basin is partly enclosed, exhibiting in the neighborhood of Chalons and Rheims some most beautiful examples of river adjustment in structures of this kind. There is the great escarpment that is retreating southeastward in Wurtemberg from the plateau of the Black forest in Baden.

With change of dip in the strata on which the escarpment is developed, we pass from examples of horizontal structure to others of more and more tilted structure. Under the first of this series, we find initial escarpments in the walls of the Grand canyon of the Colorado, and almost extinguished escarpments in those sandstone-capped buttes which are so common on the Great plains, with innumerable examples at intermediate stages. In structures of a more decided dip the escarpment becomes a ridge, and the waterways through it become water-gaps, like those of Pennsylvania and further southwest. Thus introduced, these typical transverse valleys may be easily understood, and a proper understanding of the relations of longitudinal and transverse valleys may gradually supplant the misunderstanding now so generally current.

With the more complete retreat of an escarpment the frequently unconformable foundation-mass is revealed, and way is thus opened for the explanation of superposed rivers and valleys, of which we have so many interesting examples in the eastern part of the country. Thus so simple a matter as our coastal ridges may lead into a great variety of relations and over a great part of the world.

In the same way there is the question of the typical meanders of rivers on their flood-plains and the inherited meanders of rivers in deep gorges, of which many examples might be quoted. The whole problem of baseleveling and massive elevation is thus encountered. Again, there are those peculiar small rivers following large valleys, so aberrant from the normal river system, in which a just proportion between the river and its valley is precisely observed. With these one of the many entrances to the glacial problem is effected. The variety of illustrations of the theme is endless; it is only a question of the number of pages that should be here allotted to it.

Reports of the kind thus indicated might not be frequently consulted by the professional geologist, the mining engineer or the paleontologist, but they would constitute attractive chapters to a great number of inquiring teachers. They might even attract the attention of non-professional but intelligent citizens who would otherwise know of the state survey reports only as odd volumes, received occasionally from the local representative in the legislature and stowed away in the under part of a bookcase. It is certainly desirable that the interested attention of many persons should be drawn thus to the reports of the surveys in order to create a strong public sentiment for their steady continuance. While the teachers of a state are not, as a rule, of great political influence, it is only their own fault if they cannot make themselves heard where their own interests are involved. I believe that they would make themselves heard if their interest were once awakened in this question, and that there is no other division of the community that can at once serve and be served by the state surveys so effectually.

In order to gain a sufficient circulation of the geographical chapters of the survey's annual reports an arrangement should be entered into with the superintendents of public instruction whereby these chapters should be reprinted in the public school reports, and, if possible, struck off as "separates" for general distribution to all high-school teachers. If well written and well illustrated they

could not fail to create a demand for more material of the same kind. Later reports in succeeding years would be looked for with expectant interest. The subject of school geography would be greatly enriched; the enriching influence would work downward into the lower schools; it would in time make its appearance in new text books. The new geography would hardly be recognized by those who had studied only the old geography, in which merely descriptive or statistical accounts of boundaries, capes, river branches and mountain heights constitute too large a proportion of the subject-matter.

The cost of an effective geographical chapter in an annual report need hardly be so great as to be prohibitive. A month or two of field work and perhaps as much more in office work should suffice for an experimental beginning. The processes of outdoor photography and of reproduction of photographic plates are now so greatly simplified and cheapened that good illustrations are within reach at moderate expense. The report once prepared, the cost of striking off additional thousands of reprints is relatively trifling.

It has been suggested that work of this kind could not be undertaken by reason of the want of geographical assistants. Such a want would not exist long if it were announced. Ten or fifteen years ago there were no petrographers. Now the educational market is well stocked with them, and the change shows how prompt the educational supply will respond to the professional demand. There is no reason to think that a demand for geographical assistants would not be met in a few years. Competition would soon improve the quality if it were not high enough at first.

It is of course not to be expected that geographical work will be taken up largely at once. Some of the state surveys might not be allowed to undertake it by the terms of the law under which they are now working. Others might be fully engaged in certain problems from which they could not for some time spare either men or money; but among them all it is to be hoped that a few may in the course of the next year or two enter on this attractive and popular field, feeling their way, as it were, in the public mind. For one, I feel confident that the public mind will welcome their work.

The next paper by the same author was illustrated by lantern views.

## *FACETTED PEBBLES ON CAPE COD*

BY WILLIAM M. DAVIS

The paper was discussed by G. K. Gilbert, N. S. Shaler and the author. An abstract of the paper, with the discussion, is published in The American Geologist, volume xiii, February, 1894, page 146. The full paper is published in the Proceedings of the Boston Society of Natural History, volume xxvi, 1893, pages 166–175.

The lantern views in illustration of the next paper were presented by Professor Davis, and the sections and maps by Mr Griswold.

## *EASTERN BOUNDARY OF THE CONNECTICUT TRIASSIC*

BY W. M. DAVIS AND L. S. GRISWOLD

This paper is printed as pages 515–530 of this volume.

The following paper was read by title:

*PALEOZOIC INTRA-FORMATIONAL CONGLOMERATES*

BY CHARLES D. WALCOTT

This paper is printed as pages 191–198 of this volume.

The Society then adjourned for the day. In the evening the annual dinner was served at the Thorndike hotel. Brief speeches were made by the greater number of Fellows in attendance at the meeting.

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## Session of Friday, December 29

The Society was called to order at 10 o'clock a m in the hall of the Boston Society of Natural History, President Dawson in the chair.

The Secretary read the following:

### *REPORT OF THE COUNCIL*

*To the Geological Society of America,*
*in Sixth Annual Meeting assembled:*

During the past year the Council has held three meetings; one at Ottawa in conjunction with the winter meeting of the Society, at which four sessions were held, but not a quorum of the Council present. In April a meeting was held in Washington, with the President and a quorum present; and the summer meeting, with three sessions, was held in August in Madison, Wisconsin.

The work of administration of the Society will be shown in the following reports of the officers:

#### Secretary's Report

*To the Council of the Geological Society of America:*

A large part of the work of the Secretary becomes evident to the Fellowship in the regular course of administration through receipt of printed matter. The correspondence is large, about 500 letters having been written during the year. It has become necessary to employ a stenographer regularly for part of each day.

*Membership.*—During the past year the Society has fortunately lost no Fellows by death. The latest printed roll of membership bears the names of 233 living and nine deceased Fellows. At the Madison meeting five men were elected and all have qualified, as follows: Sandford Fleming, C. H. Gordon, C. A. Hollick, T. C. Weston, A. A. Wright. By application of the rules the names of eleven Fellows may be dropped

from the roll for non-payment of dues. Two resignations have been accepted. Four candidates for Fellowship are now before the Society, and fourteen nominations are awaiting action by the Council.

*Bulletin Distribution.*—With volume 2 the plan of binding the whole edition in brochure covers was discontinued. Of volumes 3 and 4 only 250 copies of each brochure were bound, besides the 30 copies for the author. The remainder of the edition was held in sheets and distributed to the subscribers and exchanges entirely unbound. In every way this is a more economical and convenient plan, and the forms are in perfect condition for volume binding. As will be seen in the following table the losses of brochures have been reduced to a minimum, and the five copies of each brochure at present left over have proved sufficient to meet demands of sales and deficiencies.

The Secretary's books show the disposition of every volume and every brochure that has left his possession.

The brochure plan of publication seems to meet with general approval. No criticisms of the plan have been received. However, the majority of subscribers prefer to receive the volume complete. Nine "exchanges" in the United States and one in Canada receive the brochures, and twenty-one libraries in the United States.

The following tables show the disposition of the four published volumes:

*Bulletin Distribution from the Secretary's Office during 1891-1893*

COMPLETE VOLUMES

| | Vol. 1. | Vol. 2. | Vol. 3. | Vol. 4. |
|---|---|---|---|---|
| In reserve | 90 | 334 | 380(?) | 385(?) |
| Donated to institutions ("exchanges") | 82 | 82 | 81 | 81 |
| Held for "exchanges" | 9 | 9 | 10 | 10 |
| Sold to libraries, etc. | 63 | 64 | 61 | 57 |
| Sold to Fellows | 12 | 10 | 4 | .. |
| Sent to Fellows to supply deficiencies | 2 | 1 | 1 | .. |
| Donated | 4 | 4 | 2 | 1 |
| Bound for office use | 2 | 2 | 2 | 2 |
| Distributed to Fellows in brochures as issued | .. | . | 209 | 214 |
| Number of complete copies received | 264 | 506 | 750(?) | 750(?) |

BROCHURES

| | Vol. 1. | Vol. 2. | Vol. 3. | Vol. 4. |
|---|---|---|---|---|
| Sent to Fellows to supply deficiencies | 44 | 109 | 23 | 11 |
| Sent to libraries to supply deficiencies | | 7 | 3 | 1 |
| Sold to Fellows | 6 | 7 | 1 | 3 |
| Sold to the public | 6 | 18 | 5 | 7 |

In explanation it should be said that the edition of volume 1 was only five hundred copies, and that the first two volumes were sent to the Fellows directly from the printers; also that the stock of volumes 3 and

4 have not been wholly unpacked. It is found more convenient to make the tables cover the whole distribution from the Secretary's office during the three years. A comparison of last year's report with this will give the details for the past year.

*Subscribing Institutions.*—At different times circulars descriptive of the Bulletin and offering it at the five-dollar rate have been sent to most of the libraries in America and Europe. A few orders have been received from foreign book dealers. Some of these orders may be for individuals, as the price to persons living outside of this continent was lately reduced to five dollars. The known subscribers are all in the United States. Upon the books of the Secretary there are 44 permanent subscribers, 26 receiving the volumes complete and 18 the brochures. The books also bear the names of 14 institutions or dealers which have made special or limited subscriptions, usually for single volumes, in advance. The orders which have been received for volumes previously published are not here included.

*Bulletin Sales.*—The Secretary's books show the details of the sales of the Bulletin. The receipts are deposited with the Security Trust Company, subject to the check of the Treasurer, and draw 4 per cent interest. The financial result is given in the following table:

*Receipts from Sale of Bulletin during 1893.*

BY SALE OF COMPLETE VOLUMES.

| | Vol. 1. | Vol. 2. | Vol 3. | Vol. 4. | Total. | |
|---|---|---|---|---|---|---|
| From Fellows........ | $4 50 | $4 50 | $12 00 | ...... | $21 00 | |
| From libraries, etc... | 45 00 | 45 00 | 150 00 | $195 00 | 435 00 | |
| Total for 1893.... | 49 50 | 49 50 | 162 00 | 195 00 | 456 00 | |
| By last report (1892).. | 299 60 | 296 50 | 146 50 | 15 00 | 757 60 | |
| Total to date..... | $349 10 | $346 00 | $308 50 | $205 00 | | $1,213 60 |

BY SALE OF BROCHURES.

| | Vol. 1. | Vol. 2. | Vol. 3. | Vol. 4. | Total. | |
|---|---|---|---|---|---|---|
| From Fellows........ | $1 25 | $2 35 | $0 30 | ...... | $3 90 | |
| From the public ..... | 6 45 | 3 65 | 75 | $4 70 | 15 55 | |
| Total for 1893.... | 7 70 | 6 00 | 1 05 | 4 70 | 19 45 | |
| By last report (1892).. | 4 55 | 6 05 | 2 65 | ...... | 13 25 | |
| Total to date..... | $12 25 | $12 05 | $3 70 | $4 70 | | $32 70 |

| | |
|---|---|
| Grand total........................................... | $1,246 30 |
| Received for volume 5, in advance ......................... | 15 00 |
| Total receipts to date........................................ | $1,261 30 |
| Amount charged and uncollected (mostly volume 4).......... | 131 50 |
| Total Bulletin sales to date ................................. | $1,392 80 |

*Exchanging Institutions.*—The Council in 1891 prepared a list of institutions to which the Bulletin was offered as a gift. Eighty-one institutions have accepted the volumes. The list should soon be published, with a description of the considerable literature that they have sent to the Society. The purpose of the Council being to place the Bulletin so as to make it accessible to geologists the world over, the institutions are widely distributed, as follows: United States, 15; British America, 7; South America, 3; Great Britain and Ireland, 8; Europe, 37; Asia, 3; Africa, 1; Australasia, 6; Hawaiian Islands, 1.

*Cost of Administration.*—The work of the Secretary's office is conducted with scrupulous regard for economy and the interests of the Society. A minute account is kept of all expenses, and with each bill is sent a transcript of the book account. The account is absolutely distinct from that of money received for the Bulletin. A set of books shows each day the condition of the various departments. The following statement covers the fiscal year of 1893 as nearly as can be made without dividing single vouchers:

*Expenditure of Secretary's Office for the Society's Fiscal Year (approximately), November 30, 1892, to November 30, 1893*

ACCOUNT OF ADMINISTRATION

| | | |
|---|---|---|
| Clerk | $87. 26 | |
| Traveling and hotel | 118 43 | |
| Postage and telegrams | 36 88 | |
| Stationery and records | 21 83 | |
| Printing | 96 05 | |
| Meetings | 27 35 | |
| Library | 2 75 | |
| Total for Secretary | $390 55 | |
| Printing for the Treasurer | 2 00 | |
| Total | | $392 55 |

ACCOUNT OF BULLETIN

| | | |
|---|---|---|
| Postage | $123 60 | |
| Expressage | 79 56 | |
| Envelopes and wrapping | 25 70 | |
| Printing | 35 55 | |
| Collection of checks | 1 95 | |
| Total for Secretary | $266 36 | |
| Printing and binding for the Editor | 6 75 | |
| Total | | $273 11 |
| Total expenditure | | $665 66 |

*Work of the Society.*—The following table includes the papers and abstracts of papers, of whatever length, printed in the four completed volumes of the Bulletin. The few titles not accompanied by descriptive matter or discussion are not included. As such a classification of papers, many of them being of a general or composite character, must vary somewhat with the individual judgment, the table cannot be regarded as wholly accurate. It may indicate approximately the attention given to different branches of geologic science.

*Classification of Papers and Abstracts contained in the Bulletin, Volumes 1–4.*

| Character of Papers. | | Number of Papers. |
|---|---|---|
| Biographic and Historical | | 11 |
| Physical and Structural Geology | | 27 |
| Glacial Geology | | 21 |
| Stratigraphic Geology: | | |
| Archean (pre-Paleozoic) | 8 | |
| Paleozoic | 19 | |
| Mesozoic | 11 | |
| Tertiary | 10 | |
| Pleistocene | 12 | |
| | —— | 60 |
| Paleontologic Geology: | | |
| Paleozoölogy | 15 | |
| Paleobotany | 5 | |
| | —— | 20 |
| Lithologic and Mineralogic Geology | | 18 |
| Physiographic Geology | | 4 |
| Cartographic Geology | | 2 |
| Archeologic Geology | | 1 |
| Economic Geology | | 8 |
| Total number | | 172 |

Respectfully submitted,

H. L. FAIRCHILD,
*Secretary.*

ROCHESTER, N. Y., *December 22, 1893.*

### Treasurer's Report

*To the Council of the Geological Society of America:*

In accordance with the By-Laws, a condensed statement of the operations of the Treasury for the year ending November 30, 1893, is hereby submitted:

RECEIPTS

| | | | |
|---|---|---|---|
| Balance in Treasury November 30, 1892 | | $601 15 | |
| 184 Fellowship fees | | 1,840 00 | |
| Initiation fees, 8 | | 80 00 | |
| Interest on investments | | 150 15 | |
| Sales of publications | | 598 05 | |
| Assessments on cost of publications | | 2 00 | |
| Bank time certificates cashed | | 588 55 | |
| | | | $3,859 90 |

DISBURSEMENTS

| | | | |
|---|---|---|---|
| Expenses of Secretary's office: * | | | |
| On account of administration | $368 45 | | |
| On account of Bulletin | 245 80 | | |
| | | $614 25 | |
| Expenses of Editor's office | | 36 95 | |
| Printing account, circulars, et cetera | | 11 50 | |
| Bulletin publication: | | | |
| Printing account | | 1,674 19 | |
| Engraving account | | 175 25 | |
| Photograph account | | 11 67 | |
| Investment account | | 700 00 | |
| A. H. Cole on account of error in assessment of last year | | 3 00 | |
| | | | $3,226 81 |
| Balance in Treasury November 30, 1893 | | | $633 09 |

Respectfully submitted,

I. C. White,
*Treasurer.*

### Editor's Report

*To the Council of the Geological Society of America:*

The duties of editor were assumed by me in January, 1893, the position having been accepted subject to the condition that if I should be absent in Europe several months on official business the work was to be carried on by the former editor, Mr McGee. This absence became necessary,

* The figures given for this item in the Treasurer's report are for expenses *paid* up to November 30. The figures given in the Secretary's report include expenses *incurred* up to November 30, although paid later; also two items for Treasurer aud Editor.

and volume 4, which has been issued during the past year, was editorially the joint product of Mr McGee and myself.

A contract was made with Judd & Detweiler, of this city, at reduced rates, for the composition and press-work of volume 4, and as their work has been unusually satisfactory, the contract has been continued for volume 5.

It has not been found practicable to make a contract with an engraving company for the reproduction of illustrations. The cost of such reproduction is a variable quantity, conditioned by the character of the object to be reproduced. The services of the Moss Engraving Company were continued for volume 4, and a rigid supervision was exercised over both the character of their work and the prices charged, and it is believed that good results were obtained at rates that compare favorably with the usual market prices.

For volume 5 the attempt has been made to secure even better results at cheaper rates. Thus far two pieces of line work have been submitted to the Standard Engraving Company of Washington, D. C. The cuts have been satisfactory both in quality and cost.

The cost of each of the four volumes thus far issued by the Society is as follows:

| | Vol. 1. (pp. 593; pl. 13.) | Vol. 2. (pp. 662; pl. 23.) | Vol. 3. (pp. 541; pl. 10.) | Vol. 4. (pp. 458; pl. 10.) |
|---|---|---|---|---|
| Letter-press......... | $1,473 77 | $1,992 52 | $1,535 59 | $1,286 39 |
| Illustrations ... .... | 291 85 | 463 65 | 383 35 | 173 25 |
| | $1,765 62 | $2,456 17 | $1,918 94 | $1,459 64 |

The last brochure of volume 4 went to press September 23.

Up to the date of this report 70 pages of volume 5 have been published. These 70 pages represent the "Proceedings of the Madison Meeting," and Professor Stevenson's paper, "Origin of the Pennsylvania Anthracite." This last paper was issued November 22, since which time no material has been received from members for publication.

I feel it to be a duty which I owe to the administration of the office of Editor, as well as to the best interests of the Society, to urge upon the Fellows the desirability of putting their manuscripts in the best possible form before presenting them for publication. The task of editing the mass of material which the Society annually puts through the press is not a light one, and its arduousness can be greatly curtailed by the author furnishing at least legible manuscript. Aside from this consideration, it is of great advantage to authors themselves by promoting accuracy in the publication of their papers. There are many proper names, technical terms, citations and quotations with which even an editor may not be personally acquainted or which he may not be able to verify, and if the

manuscript has been carefully prepared and proof read by the author much time and many errors will be saved. The question of rapid publication affecting the interests of the Society is also involved, and from every standpoint the editor has a right to demand from members all the aid which can result from carefully prepared manuscripts.

Respectfully submitted,

J. Stanley-Brown,
*Editor.*

Washington, D. C., *December 18, 1893.*

The Council submits to the Society the following recommendations:

(1.) In consideration of his eminent services to the Society in establishing the Bulletin and in editing the first three volumes thereof, the Council recommends that Mr W J McGee be elected a Life Member of the Society.

(2.) The Council recommends that the Editor be paid an annual sum of $160, the same to cover clerical assistance, postage, expressage, stationery, traveling expenses and hotel expenses at the meetings, and all other expenses incidental to the office of Editor.

(3.) The Council recommends that an annual payment be made to the Secretary of $300, the same to cover personal expenses for clerical assistance and attendance upon meetings of the Council or the Society.

Respectfully submitted,

The Council.

The Council Report was as a whole adopted by unanimous vote.

The Secretary presented a communication relating to a proposed exploration of Ellesmere Land, in the Arctic ocean, accompanied by a recommendation from the Council that the Society approve the project. The matter was discussed and finally by vote referred back to the Council.

Professor I. C. Russell, Chairman of the special committee on the matter of observations of glaciers proposed by the Alpine Club, made an oral report and the committee was discharged at its own request.

The following resolution was referred to the Council:

*Resolved,* That the Council be requested to consider means of expediting the formal business matters usually presented at the meetings of the Society.

For the Auditing Committee, I. C. Russell reported the Treasurer's accounts as correct. The report was adopted and the committee discharged.

The annual address of the President was read from the chair:

*SOME RECENT DISCUSSIONS IN GEOLOGY*

ANNUAL ADDRESS BY THE PRESIDENT, SIR J. WILLIAM DAWSON

This address is printed as pages 101-116 of this volume.

Following the address by the President the papers announced upon the printed program were taken up, and the first one in order was—

*THE CRETACEOUS FAUNAS OF THE SHASTA-CHICO SERIES*

BY T. W. STANTON

Remarks upon the communication were made by Alpheus Hyatt and Henry M. Ami. This paper was combined with the one by J. S. Diller, entitled The Shasta-Chico Series, and, under their joint authorship and the latter title, was printed as pages 434–464 of this volume.

The next paper was—

*GEOLOGY OF PARTS OF TEXAS, INDIAN TERRITORY AND ARKANSAS ADJACENT TO RED RIVER*

BY ROBERT T. HILL

The paper is printed as pages 297–338 of this volume.

During the reading of Professor Hill's paper a recess was taken for dinner.

The following paper was read by title:

*GEOLOGICAL SKETCH OF LOWER CALIFORNIA*

BY S. F. EMMONS AND G. P. MERRILL

This paper is printed as pages 489–514 of this volume.

In the absence of the author the following paper was read in abstract by W. M. Davis:

*ORIGIN AND CLASSIFICATION OF THE GREENSANDS OF NEW JERSEY*

BY WILLIAM B. CLARK

This paper is published in the Journal of Geology, volume ii, 1894, pp. 161–177.

The following paper was read by title:

*CRUSTAL ADJUSTMENT IN THE UPPER MISSISSIPPI VALLEY*

BY CHARLES ROLLIN KEYES

This paper is printed as pages 231–242 of this volume.

The next paper was—

*A GEOLOGICAL STUDY OF LAKE MOHONK AND LAKE MINNEWASKA, NEW YORK*

BY WILLIAM H. NILES

Remarks were made by M. R. Campbell and N. S. Shaler.

The following paper was presented by Professor Richards, of the Institute of Technology, who was introduced to the Society by Professor Niles:

*A PRISMATIC STADIA TELESCOPE*

BY ROBERT H. RICHARDS

Remarks were made upon the paper by H. F. Reid. The paper is published in The Journal of the Association of Engineering Societies, volume xiii, January, 1894.

The following two papers were read conjointly:

*ORIGIN OF THE COARSELY CRYSTALLINE VEIN GRANITES OR PEGMATITES*

BY WILLIAM O. CROSBY

Remarks were made by Alfred C. Lane and the President. An abstract is published in The American Geologist, volume xiii, March, 1894, page 215.

*A CLASSIFICATION OF ECONOMIC GEOLOGICAL DEPOSITS, BASED UPON ORIGIN AND ORIGINAL STRUCTURE*

BY WILLIAM O. CROSBY

This paper is published in full in The American Geologist for April, 1894, pages 249–268. It will also appear in a future issue of the "Technology Quarterly."

The following paper was read by title:

*LAKE CAYUGA A ROCK BASIN*

BY RALPH S. TARR

This paper is printed as pages 339–356 of this volume.

The next paper was read, in the absence of the author, by L. S. Griswold:

*PLEISTOCENE PROBLEMS IN MISSOURI*

BY JAMES E. TODD

This paper is printed as pages 531–548 of this volume.

The last paper of the afternoon session was the following:

*REMARKS UPON A SUPPOSED GLACIATED STONE AXE FROM INDIANA*

BY G. FREDERICK WRIGHT

Remarks were made by W. H. Niles, T. C. Chamberlin, the President and others. A notice is published in The American Geologist, volume xiii, 1894, page 217.

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## Session of Friday Evening, December 29

The Society convened at 8 o'clock, President Dawson presiding.

The following five papers were read without interruption, and discussion reserved until all of them were before the Society.

*PSEUDO-COLS*

BY T. C. CHAMBERLIN

An abstract of this paper is published in The Journal of Geology, volume ii, page 205, and in The American Geologist, volume xiii, March 1894, page 217.

The second paper was read by the senior author.

*CERTAIN FEATURES OF THE PAST DRAINAGE SYSTEMS OF THE UPPER OHIO BASIN*

BY T. C. CHAMBERLIN AND FRANK LEVERETT

An abstract of this paper, with the discussion, is published in The American Geologist, volume xiii, March, 1894, page 217.

The third paper was:

*GLACIAL HISTORY OF WESTERN PENNSYLVANIA*

BY G. FREDERICK WRIGHT

An abstract of this paper is published in The American Geologist, volume xiii, March, 1894, page 219.

The fourth paper was read by title.

## *THE ANCIENT STRAIT AT NIPISSING*

BY F. B. TAYLOR

*Contents.*

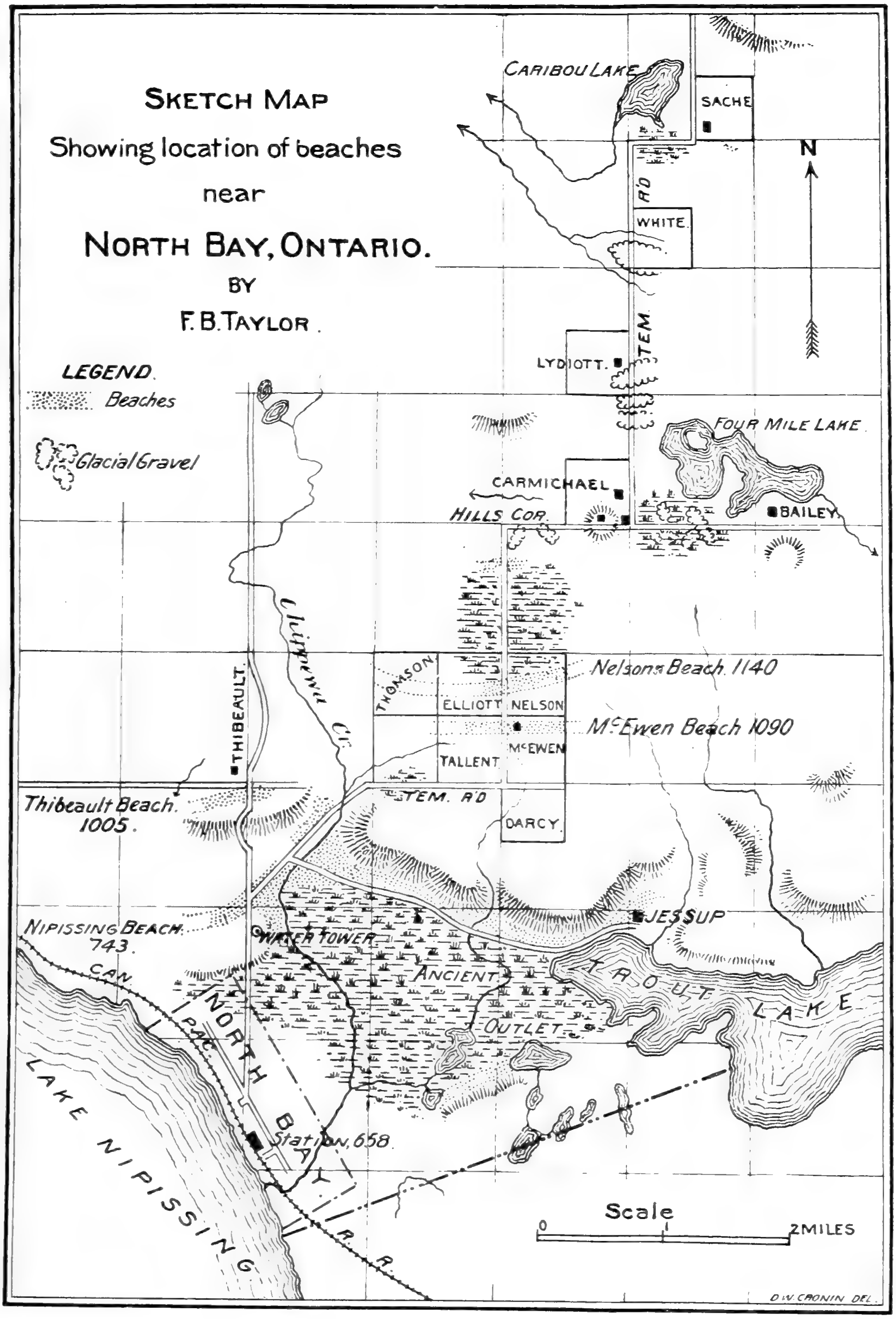


### Introduction.

One of the most interesting and significant chapters of modern geologic research in America has been the gradual unfolding of the story of postglacial changes of the Great lakes. Deserted shorelines have been traced with more or less continuity around all their coasts and several abandoned outlets are already well known. It was my privilege recently to visit the site of one of these and bestow some study on its appearance and surroundings. First in August, and again in September of the season just past, I went to North bay, in the Province of Ontario, to see the country in the vicinity of the ancient outlet at lake Nipissing. In August I was accompanied by Dr F. Savary Pearce of Philadelphia. It is the object of this paper to give a short description of what was observed on those occasions. On account of limited time and the roughness of the country it was not possible to make more than a brief reconnaissance, and it was partly because of the indecisive results of the first visit that the second one was made.

The existence formerly of an outlet for the Great lakes at lake Nipissing had been regarded by me as an established fact; but it was still an open question whether the waters of the great postglacial submergence rose above the level of the outlet river. The only information on the subject which had ever come to my knowledge was from a conversation with Mr G. K. Gilbert at Indianapolis, in August, 1890. Mr Gilbert had then just returned from lake Nipissing and had examined the bed of the ancient outlet. He expressed his belief in the existence of the river and added that he thought he saw terraces on the hills back of North bay at an altitude of 200 to 300 feet above the lake, but that he had not examined them closely. This agreed in a general way with an hypothesis which I had entertained for some time previous and according to which I had estimated the probable height of the highest shoreline at lake Nipissing at an altitude of at least 400 feet. To pursue this inquiry was the chief object of my visits.

My measurements were made with an aneroid; but care was taken to determine the weather variation and eliminate it as far as possible. The datum for the localities near North bay was the Canadian Pacific railway station at that place. On the profile of the road this is given as 635 feet above the "Summer level of




SKETCH MAP OF A PORTION OF ONTARIO.

the Saint Lawrence at Montreal." The latter I found by Doctor Spencer's table of altitudes in Canada to be 12 feet above high tide in lake Saint Peter, or 23 feet above mean tide level, making the station at North bay 658 feet above the sea. The level of lake Nipissing is a trifle less than 15 feet below the station, but according to the Canadian Geological Survey* lake Nipissing is 665 feet above sealevel. By the same authority it is stated that levels were run from Trout lake to lake Nipissing, showing the former to be 25 feet above the latter, and that the height of land on the portage from Trout lake to the Riviere a la Vase, which flows into lake Nipissing, is 24½ feet above Trout lake; but I have used the Canadian Pacific railway levels, which would make lake Nipissing about 20 feet lower. I am indebted to Mr John Bourke of North bay for an excellent map of Widdifield township, which contains all the places referred to near North bay. The location of the beaches described will be found on plate 20.

## Beaches.

### *The Nipissing Beach.*

At Mr Jessup's house, on the north side of the west end of Trout lake, a little more than four miles east-northeast from North bay, this shoreline may be seen as a delta-terrace, filling a recess in the hill where a small stream enters. Its front edge is about 50 feet above Trout lake, and its back 10 to 15 feet higher. At this place it is composed mainly of gravel, comparatively fine and free from bowlders. From this point westward it continues with the same strong character past Chippewa creek and the Temiscamang road, which is as far as the ground was seen. At the foot of the hill west of Jessups the terrace becomes a narrow shelf close to the lake, and is composed of a mass of well rounded bowlders, many of them more than a foot in diameter. For more than half a mile it retains this form, but beyond that it gradually loses its steepness in front and becomes wider and finer in composition. Toward Chippewa creek it widens still more and in a few places low beach ridges of gravel were noticed along its front.

About a mile north of North bay the flats end abruptly against the face of a terrace of bowldery drift. This terrace is a small plateau which projects southward about a mile from the foot of a high hill. It is probably of glacial origin, but it has been largely modified by the later action of waves, and possibly also to some extent by the flowing water of the abandoned outlet river. Its southward front has been eroded away in comparatively recent time, for it is still a steep, fresh bluff. Its eastern slope is more gradual and is covered by a series of well formed beach ridges, which may be seen to good advantage from the Temiscamang road about a quarter of a mile north of the water-tower. The fork of the road north of the tower is on the crest of the plateau, and also upon a gravel beach ridge which extends about half a mile northwest from that point. The altitude of this ridge is about 85 feet above the station, and the Temiscamang road follows it from the fork. The beach at the fork is a little higher than the terrace at Jessups, but not more than the proper difference between a beach and a terrace.

I did not see the slopes at corresponding levels south of the old channel, except what may be seen from the train near Callendar. At that place there is appar-

* As quoted in the "Report of Commission on Forest Preservation and National Park," etcetera, Toronto, 1893, p. 32.

ently a strong shoreline at a level corresponding to that on the north. Mr Bourke, who is familiar with the ground, indicated for me the place of a coarse gravel terrace which he has seen on the south side and which marks approximately the narrowest part of the ancient outlet.

This great shoreline is more strongly developed than any other in that vicinity above or below it, unless it be the highest line, to be mentioned later, and it seems probable that it marks the level of the Great lakes during the era of the active river outlet at Nipissing. Its level at North bay is about 743 feet above mean tide, or 160 feet above lake Huron. There is a strongly accentuated beach like this a little lower, but not widely departing from its level, at many places farther west along the shore of the North channel and the south side of lake Superior. For two spaces of about 45 miles each on the Superior shore I have traced it continuously. Its rise toward lake Nipissing indicates a slight uplift of the land in the vicinity of that lake, which must have taken place since the outlet was abandoned. The existence of this uplift is not surprising, in view of the marked warping of the Ontario highlands farther south.

### *BEACHES AT HIGHER LEVELS.*

Besides the shoreline already described in connection with the ancient river outlet there are well developed beaches at much higher levels on the hills north of North bay. Faint evidences of wave action were seen at various intermediate levels, but I will mention here only those which are well formed and conspicuous as shoreline features.

*Thibeault Beach.*—Two miles straight north from North bay the road ascends the steep face of Thibeaults hill to an altitude of about 350 feet above the station. Half a mile or more beyond is Mr Thibeault's house, at the corner of the concession line road. Just south of this corner the road crosses a beach which is composed of clean, fine, well-rounded gravel. It extends as a ridge about an eighth of a mile west-southwest from where the road crosses it, and to the east it abuts against stony ground at a slightly higher level. On the east side of the road it has been excavated for ballast, and its composition is shown to be typical fine beach gravel. This beach is about 345 feet above the North bay station, or about 1,005 feet above sealevel.

In passing up the ravine of Chippewa creek on the Temiscamang road deep deposits of rounded gravel were seen which are probably remnants of former deltas of the stream made at successively lower levels as the waters subsided.

*McEwen Beach.*—About four and a half miles northeast of North bay on the Temiscamang road and about half a mile north of Darcys corner is a beach ridge of gravel and coarse sand. It looks like the edge of a terrace when seen from the lower ground to the south, but on near approach it is seen to be a distinct ridge with a depression behind it. Its composition is disclosed in a cut at the roadside. It is a composite ridge showing two or three lines, but not very distinctly. Its altitude is about 1,090 feet above sealevel. East of the road the ground is well cleared and the house of Mr McEwen is built upon the ridge. This ridge also passes westward through the property of Mr Tallent.

*Nelson Beach.*—The McEwen beach is much surpassed by another less than half a mile farther north and about 50 feet higher. This is the highest as well as the strongest and best developed beach found on the hills north of lake Nipissing. Its altitude is about 1,140 feet above mean tide. The house and barn of Mr

Nelson are built on it east of the road. It is a broad, composite beach ridge composed of rounded gravel, rather fine, but with some pebbles and a few cobbles. To the south it faces in a series of steps of five to six feet each over the McEwen beach and the flat beyond, which drops at a distance of about two miles by a deep descent to the bed of the ancient river channel. I learned by inquiry that this gravel ridge extends westward through the lands of Messrs Elliott and Thomson and probably eastward also for a considerable distance.

The Nelson beach is in contour with a large swampy tract north of it. On the Temiscamang road this swamp is about a mile wide, but with two or three insular patches of higher ground in it. On the front of the former mainland on the north side of this swamp I found a small amount of washed, rounded gravel, but it only reached up to five or six feet, which is no higher than the top of the Nelson ridge.

### The unsubmerged Area.

This concludes the sum of the positive evidences observed on the hills north of North bay. Toward the north the country is rough, the clearings in the forest are few, and there are many swampy, almost impassable places; but my investigations did not stop at the Nelson beach. The process of making a reliable determination of the upper limit of postglacial submergence requires the gathering of negative evidences from the higher ground as well as positive evidences from below. On the first excursion on the Temiscamang road we drove north from Nelsons a mile and a quarter to Hills corner, and from there east two miles and a quarter to the farm of Mr Bailey, which is next south of Four Mile lake. Several gravel ridges were seen, but I was unable to recognize the work of waves in any of them. I am quite sure they were all glacial forms. Their positions and surroundings, as well as their forms, were unlike true littoral features. About half a mile east of Hills corner there is a small, short gravel ridge which juts eastward from a drift mass somewhat after the fashion of a wave-built spit. It is composed mainly of good sized pebbles well rounded; but it is in a protected place, and the adjacent slopes at the same level, which are well cleared and easy to see, show no sign of wave action whatever. Again, half a mile east of Carmichaels corner are more fine gravel ridges. They appeared to be in the midst of a swamp, are quite irregular in form, with spurs and hollows, and they rise steeply ten to fifteen feet. I regard them as characteristic glacial forms, and they are so delicate in their structure that they could hardly have escaped modification if the waves had ever touched them. The ground along this road is most of it plentifully covered with bowlders of good size, and they are set in drift composed mainly of clay. At Baileys we were about 110 feet above the Nelson beach. By a rough estimate, without measurement, I concluded that Four Mile lake is somewhat below the level at Nelsons. Mr Bailey told me that his land was almost entirely free from bowlders. South of the road it rises in a smooth hill of almost pure clay drift which would be exposed towards the east and southeast if submerged to the level of the road.

While these negative evidences seemed fairly conclusive, they were not entirely so, for I heard of other large gravel ridges farther north on the Temiscamang road. On the second excursion I went three miles north from Carmichaels corner and half a mile east to the farm of Mr Sache, close to the east side of Caribou lake. One mile north of Carmichaels I found the gravel ridges referred to partly on the land of Mr Lydiott. They are immense irregular ridges about 40 feet high and

with a number of typical kettle holes nearly as deep. The composition was largely coarse. Another mile north, on the land of Mr White, is another gravel deposit somewhat similar and plainly of glacial origin. Near Mr Sache's house the altitude in the road is about 90 feet above the Nelson beach. The surface in that vicinity is hilly and rough and the ground is a heavy bowlder clay. The drainage is westward into Duchesnay creek, which empties into lake Nipissing.

Thus upon both positive and negative evidences of submergence, the Nelson beach was found to be the highest postglacial shoreline on the hills north of North bay.

### The south Shore of the Strait.

On the south side of the Nipissing pass the hills are much farther away, the nearest accessible point at an altitude corresponding with the Nelson beach being at Trout creek, about 28 miles south-southeast from North bay. The highest postglacial shoreline was located at Sundridge and South river, and lines a little lower were found at Trout creek. The first visit to these localities was made before the first one to North bay, and closed a two weeks' trip along the line of the Northern and Pacific Junction railway. The detailed account of those localities belongs to the record of that trip and will therefore be omitted here.

Well formed beach ridges of fine gravel were found at Sundridge facing south over the wide basin of Stony lake, which was an arm of the expanded waters at the time of the great submergence. The highest is at an altitude of about 1,205 feet above sealevel. At South river a cut terrace 50 to 60 feet above the level of an immense deposit of finely bedded clay and white silt overlain by sand was found at an altitude of about 1,220 feet. These two localities are only about five miles apart and were connected with each other and also with the ancient strait to the north. At Trout creek, 11 miles farther north, the level of the highest line at South river was not reached, but evidences of submergence were seen up to about 1,150 feet above sealevel. The failure to reach the highest line at this place was accidental and affords no just ground for presumption against the inference that a shoreline probably exists there at a slightly higher level than that at South river. The altitudes of these localities are based on the heights of the stations above lake Ontario, as given on the profile of the railroad in the engineer's office at Toronto.

The finding of the highest beach considerably higher on the south side of the Nipissing pass than on the north is rather exceptional among beaches, which almost universally rise northward; but it is not surprising when due account is taken of the very marked eastward component of differential elevation, which is well established by the observations of Dr Spencer farther south.

The ancient strait, as defined by the two highest shorelines described, was about 32 miles wide at the place of observation; but the hills draw nearer to each other toward the east, and the narrowest part of the strait was probably not less than 25 miles wide. Its depth over the low pass between lake Nipissing and Trout lake must have been more than 500 feet.

### The Ohnaping Delta.

One other locality may be appropriately mentioned in this connection. It is about eight miles east of Cartier, which is on the main line of the Canadian Pacific railway, 125 miles west-northwest from North bay. On the way east I stopped off

at Sudbury for the particular purpose of making the trip to Cartier. From Vermilion river to the summit, three miles east of Cartier, there is an ascent of 496 feet in 14½ miles, and the altitude of Cartier above mean tide is 1,363 feet. I had counted quite confidently on finding the great upper beach somewhere on this slope. On going there I found immense terraces of gravel at several elevations up to about 1,200 feet above sealevel. They are old deltas of the Ohnaping river and the smaller streams which flow into Silver lake. The railway cuts them to splendid advantage for observation and they have been excavated extensively for ballast. The country is very rough, heavily wooded and there are no roads, but the terraces can be seen distinctly from the rear platform of the train. I saw a few sand and gravel ridges near the highest level which closely resembled beaches, but could not be certain as to that. For 40 or 50 feet above the terrace at 1,200 feet there are extensive gravels filling up the stream beds. They are undoubtedly related to the ancient water-level. It seems probable, judging by similar places previously observed, that the highest beach proper is 20 or 30 feet above the level of the massive terrace at 1,200 feet.

Cartier is built upon a level gravel plain which seems to have filled an ancient lake or expanded valley. About a mile to the west against the rough hills are three distinct terraces like steps of perhaps 15 or 20 feet each. I do not know whether these forms are glacial or in what relation, if any, they stand to the great submergence.

### Ancient Nipissing Island.

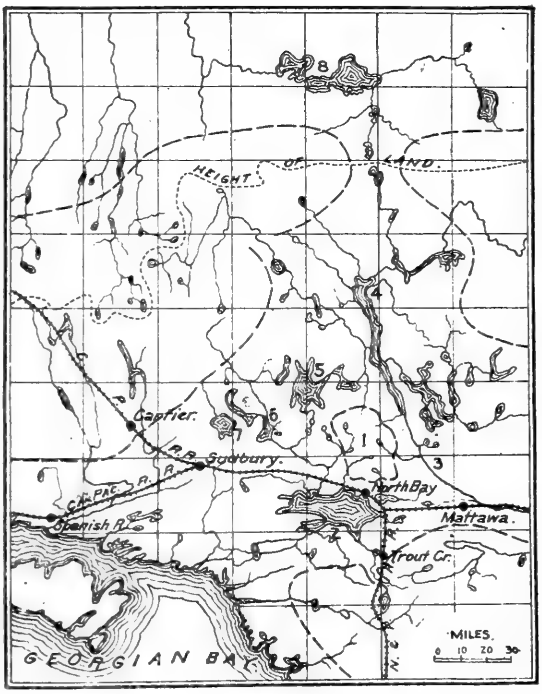



Figure 1.—*Sketch Map of part of northern Ontario.*

Showing, 1, ancient Nipissing island, with the strait to the south of it; 2, lake Nipissing; 3, the Ottawa river; lake Temiscamang; 5, lake Tamagaming; 6, lake Wagaming; 7, lake Wahnapitaeping; lake Abitibbi.

If the highest beaches here described mark approximately the contour of the shoreline of the great submergence, it must have covered a wide area of the surrounding lowlands. Upon the basis of these determinations I have sketched in figure 1 this part of Ontario, showing the location of the strait and the lake country to the north and, also in a rough and only conjectural way, the probable extent of the water in that direction. The interesting region of the northern lakes is still wild and almost unbroken; but the general character of the country is pretty well known. The altitudes of the larger lakes have been determined approximately and canoe routes are followed from one to another. The altitude of Temiscamang lake is given by the Canadian Geological Survey as 612 feet above sealevel. Lake Tamagaming, to the southwest, I did not find, but it is probably not much more than 100 feet higher. Wagaming is given at 862 feet, and Wahnapitaeping still farther southwest at 937 feet. Tamagaming is remarkable for having two outlets,

one to the north and the other to the south. It is a favorite canoe trip to go down the Mattawa from Trout lake near North bay, up the Ottawa, up the Montreal river a short distance, up the north outlet of lake Tamagaming, from this lake down its southern outlet to Sturgeon river, down this to lake Nipissing and thence back to North bay. The surveys for the James bay extension of the Grand Trunk railway were going on during the past season northward from North bay. From Mr J. C. Bailey, of Toronto, who had charge of the work, I learned much concerning the character of the country, and especially of the region surrounding lake Tamagaming. The divides northeast and south of this lake are not high. To the north of North bay for perhaps 40 to 50 miles the land about the sources of the Little Sturgeon, Antoine and Jocko rivers is high; but considering the low altitude of lake Temiscamang and the others southwestward it seems a pretty safe conjecture that the high tract north of Nipissing strait was a large island, and that it was bounded toward the east by a broad expanse of water overlying the upper Ottawa, toward the north by a wide strait overlying lake Tamagaming, and to the west by an open water surface extending nearly to Cartier. Dr Bell gives the altitude of lake Abittibi as 857 feet and of the pass over the Height of Land between lakes Temiscamang and Abittibi as 957 feet above sealevel.

### Conclusions.

The belief which I ventured to express in a previous paper * has in the main been verified. At their highest level the Great lakes had open connection with waters to the east through a broad strait at Nipissing, and it now seems probable that they had another to the northeast. It is not yet proved that these connections were with the ocean, but I believe the evidence tends more and more strongly toward that conclusion. The glacial hypothesis was plausible and useful, but as exploration has progressed it has been found necessary to put the ice dams farther and farther back, until it now seems fair to say that the burden of proof rests with those who favor them.

In view of these facts, I express again, and with increased confidence, the belief that the Iroquois beach and the highest beaches in the lower Saint Lawrence, Champlain, Hudson and Ottawa valleys, and in the basins of lakes Huron, Michigan and Superior, and also in the valley of the Red river of the North, are all one continuous shoreline of the sea.

Fort Wayne, Indiana.

The fifth paper was—

## *EXTRAMORAINIC DRIFT BETWEEN THE DELAWARE AND THE SCHUYLKILL*

BY EDWARD H. WILLIAMS, JUNIOR

This paper is printed as pages 281–296 of this volume.

Following the presentation of these five papers there was an animated discussion, participated in by the authors present. Remarks were also made by I. C. White and President Dawson.

* "The highest Old Shore Line on Mackinac Island," Am. Jour. Sci., 3d series, vol. xliii, March 1892, pp. 216 and 218.

The following three papers were read by title, in the absence of the authors.

### *INTERGLACIAL SERIES OF GERMANY*

BY DR ALFRED JENTZSCH, KÖNIGSBURG, PRUSSIA

This paper is published in full in The American Geologist, volume xiii, March, 1894, page 221.

### *THE MADISON TYPE OF DRUMLINS*

BY WARREN UPHAM

### *DIVERSITY OF THE GLACIAL DRIFT ALONG ITS BOUNDARY*

BY WARREN UPHAM

Abstracts of the papers by Mr Upham are published in The American Geologist, volume xiii, March, 1894, pages 222–223.

The following paper was read:

### *MICROSCOPIC STRUCTURE OF SILICIOUS OÖLITE*

BY E. O. HOVEY

*Contents*



#### Silicious Oölite from Pennsylvania.*

In the American Journal of Science † for September, 1890, Messrs E. H. Barbour and J. Torrey describe a silicious oölite from near State College, Center county, Pennsylvania, giving chemical analyses and figures of microsections of the rock. The microscopic characters described by Dr Barbour are practically summed up in the following quotation from his article:

> "A fractured surface of the silicious variety exposes the component spherules in section, showing their concretionary structure, their concentric coats of alternately lighter and darker color, deposited around real or imaginary centers. In many, organic remains are the nuclei; in others, crystals or fragments of inorganic matter."

The author quoted does not seem to have used polarized light in studying his sections, and as the use of this medium reveals the structure of the rock very clearly and brings out some points not mentioned in the article to which the reader is referred, it seems worth while to add some observations to those already published.

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* My thanks are due to Mr L. V. Pirsson, of the Sheffield Scientific School, not only for the specimen and section on which this investigation was made, but also for valuable suggestions during its progress.

† Vol. III, xl, pp. 246–249.

The "crystals or fragments of inorganic matter" are of quartz. Sometimes the nucleus consists solely of a rounded fragment of a quartz crystal. In other spherules the nucleus is such a fragment surrounded by finely granular quartz; other nuclei, again, consist entirely of finely granular quartz. The most interesting nuclei are those which contain a secondarily enlarged fragment. These are numerous, some showing a single zone of secondary enlargement, others showing more than one. The first zone of such growth is always cloudy from impurities taken up in process of deposition. If there is a second zone, it is of clear quartz, like the central fragment. The enlargements are oriented in the same way as the center and occasionally are somewhat indistinctly bounded by crystal planes,* though the tendency is to grade off into granular quartz. The grains of this granular quartz are from 0.04 to 0.06 millimeters in diameter. The large nuclear fragments look like granitic quartz on account of their richness in fluid inclusions, and some of them contain minute acicular crystals of rutile (?).

No organic remains were observed by the present writer in the section studied by him.

The principal part of each spherule is made up of a series of very thin colorless and light brown rings deposited concentrically around the nucleus. Between crossed nicols this portion is seen to be composed of minute fibers arranged radially, but the fibers do not extend across from one ring to another, and are, therefore, so short that the whole appears granular instead of fibrous. The optically negative character of this material shows that it is chalcedony. Between this zone and the nucleus a belt of much longer chalcedony fibers is occasionally observed. The outer coating of each spherule is a thin shell of colorless chalcedony, which is so fine grained as to be almost aphanitic in texture, when seen in polarized light. This shell is usually sharply defined from the interior of the spherule as well as from the matrix, both in ordinary and in polarized light. It is from 0.04 to 0.06 millimeters in thickness, forming from $\frac{1}{18}$ to $\frac{1}{11}$ of the total diameter. The spherules are very symmetrical in shape and vary from 1 millimeter to 1.5 millimeters in diameter, though an occasional oblong one is larger.

Outside the spherules in many instances and concentric with them, though forming a part of the matrix, are incomplete, simple or complex fibrous shells of chalcedony, referred to by Doctor Barbour as "agatized bands." The fibers have their long axes normal to the sphere on which the shell occurs, and they frequently extend through several bands. Some of the cuspidate spaces between the spherules are completely filled with this form of chalcedony, the fibers all being normal to the surface of the nearest sphere; others have an apparently granular filling, which shows a tendency toward aggregation into minute spherules, which possess the characteristics of chalcedony and which rarely show any concentric bands. The larger grains in the matrix are quartz.

The chemical analyses given in Barbour and Torrey's article would indicate that the spherules are almost chemically pure silica, and that all the impurities are in the matrix; but dissolving agents have attacked the former the most vigorously, leaving their outer portions—the minutely fibrous chalcedony—a brown ochreous mass and causing them to drop out of the almost unaffected matrix.

The rock was evidently made from a clear quartz-sand by the action of alkaline waters depositing silica in the form of chalcedony around the fragments or aggre-

* On secondary enlargement of fragments of quartz crystals, see Sorby, Proc. Geol. Soc. London, 1880, p. 62; Irving, Fifth Ann. Rep. U. S. Geol. Survey, 1883–'84, p. 218.

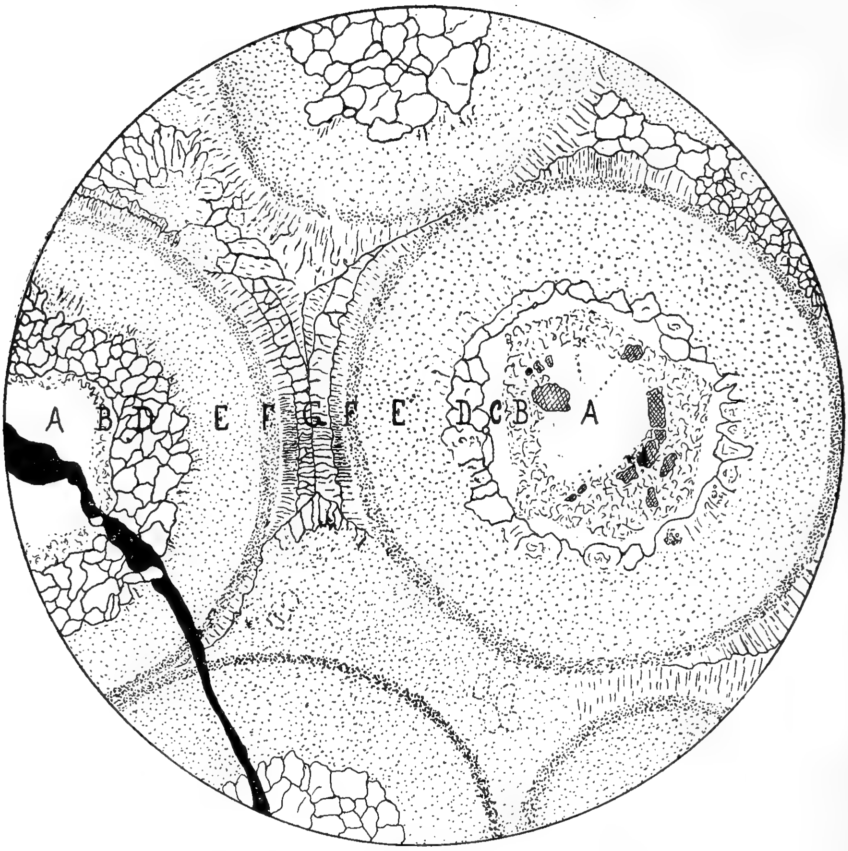


FIGURE 1.—OÖLITE FROM PENNSYLVANIA. Polarized light × 45.

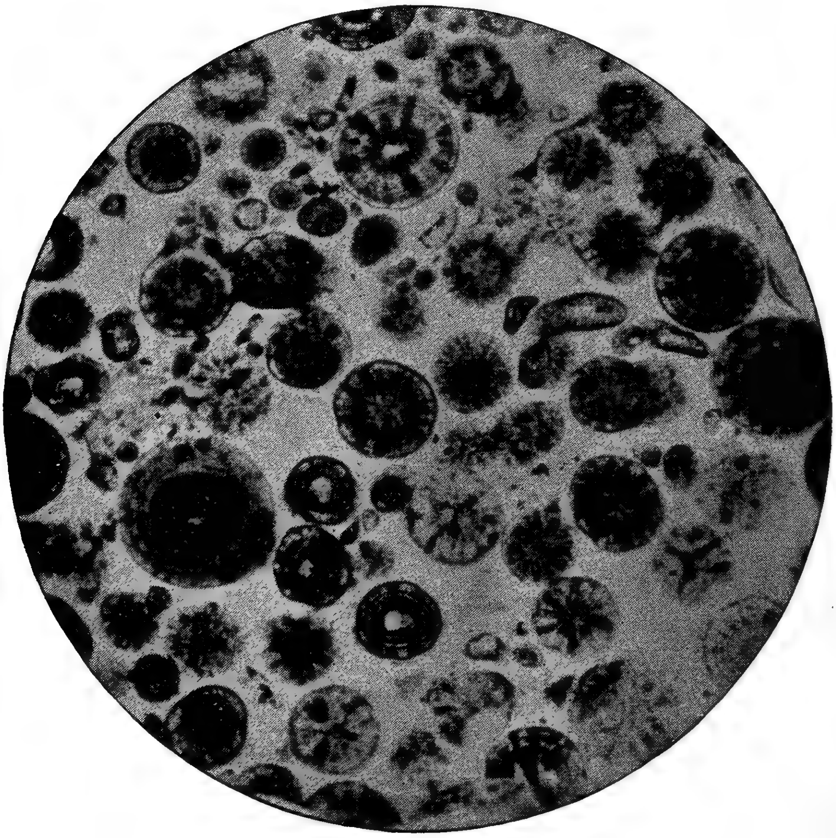

FIGURE 2.—OÖLITE FROM NEW JERSEY. Ordinary light × 24.

THIN SECTIONS OF SILICIOUS OÖLITE.

gates of fragments of quartz and making the cement between the spherules of the same substance, while some of the quartz grains were caught in this chalcedony cement without being made the nuclei of spherules.

### Silicious Oölite from New Jersey.

The writer is indebted to Professor C. E. Beecher, of Yale University, for a thin section of this rock and the photograph from which figure 2 was made. This oölite is from the Tertiary beds at an unknown locality in New Jersey. The granules are small and very irregular in size, varying from 0.12 to 0.93 of a millimeter in diameter, and vary from almost perfect spheres to much flattened ovoids and subangular bodies. The concentric structure is very pronounced in most of the granules, and many times the rings contain dark spots of indeterminate character, arranged radially to the sphere. For the most part the spheres are without apparent nuclei and are regular sphærocrystals of chalcedony. Occasionally, however, one is seen with a more or less irregular nucleus of fine grained quartz. The matrix is partly chalcedony and partly fine granular quartz, with isolated large grains of quartz scattered through it. No deposit of fibrous chalcedony as incomplete shells outside the granules was observed in this section like that so common in the Pennsylvania rock. No organic remains were noticed in the section studied.

### Explanation of Plate 21.

Figure 1.—Silicious oölite from State College, Center county, Pennsylvania. Polarized light. × 45.

*A.* Rounded fragment of clear quartz.
*B.* First zone of enlargement, cloudy quartz.
*C.* Second zone of enlargement, clear quartz.
*D.* Zone of granular quartz.
*E.* Zone of short fibrous chalcedony.
*F.* Outer shell of almost aphanitic chalcedony.
*G.* Incomplete shells of chalcedony with relatively long fibers.

The cross lined spots in the nucleus of the complete spherule seem to be of iron oxide. The broad black line in the lower left hand corner is a crack which seems to have been filled with iron oxide.

Figure 2.—Silicious oölite from New Jersey. Ordinary light. × 24.

The last paper was read by title on account of the late hour:

## *CHANNELS ON DRUMLINS, CAUSED BY EROSION OF GLACIAL STREAMS*

BY GEORGE H. BARTON

An abstract of this paper is published in The American Geologist, volume xiii, March, 1894, page 224.

At the close of the meeting, Friday evening, 10.30, the following resolution was offered by Mr J. Stanley-Brown and unanimously adopted:

*Resolved*, That the hearty thanks of the Geological Society are offered to the Boston Society of Natural History for its generous hospitality; to the Local Committee,

and especially the Chairman, Professor Wm. H. Niles, and Mrs E. H. Richards of the Institute of Technology, for their very successful efforts in providing for the comfort of the visiting members; also to President Elliot and the officers of Harvard University connected with the Museum, for the interest manifested in the Society and their efforts in its behalf.

With a few words of parting salutation the President declared the meeting adjourned.

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## Register of the Boston Meeting, 1893.

The following Fellows were in attendance upon the meeting:

F. D. Adams.
H. M. Ami.
G. H. Barton.
M. R. Campbell.
T. C. Chamberlin.
W. O. Crosby.
Whitman Cross.
N. H. Darton.
W. M. Davis.
J. Wm. Dawson.
J. S. Diller.
E. T. Dumble.
S. F. Emmons.
H. L. Fairchild.
Moritz Fischer.
H. T. Fuller.
G. K. Gilbert.
L. S. Griswold.
C. W. Hayes.
R. T. Hill.
C. H. Hitchcock.
E. O. Hovey.
H. C. Hovey.
Alpheus Hyatt.
J. P. Iddings.
J. F. Kemp.
A. C. Lane.
William McInnes.
G. P. Merrill.
W. H. Niles.
J. H. Perry.
H. F. Reid.
W. N. Rice.
I. C. Russell.
W. B. Scott.
H. M. Seely.
N. S. Shaler.
C. H. Smyth, Junior.
J. Stanley-Brown.
T. W. Stanton.
J. J. Stevenson.
R. S. Tarr.
I. C. White.
C. L. Whittle.
E. H. Williams, Junior.
G. H. Williams.
H. S. Williams.
J. E. Wolff.
G. F. Wright.

*Fellows-elect.*

A. P. Brigham.
Heinrich Ries.

Total attendance, 51.

# OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA.

## *OFFICERS FOR 1894.*

*President.*

T. C. Chamberlin, Chicago, Ill.

*Vice-Presidents.*

N. S. Shaler, Cambridge, Mass.
G. H. Williams, Baltimore, Md.

*Secretary.*

H. L. Fairchild, Rochester, N. Y.

*Treasurer.*

I. C. White, Morgantown, W. Va.

*Editor.*

J. Stanley-Brown, Washington, D. C.

*Councillors.*

(Term expires 1894.)

Henry S. Williams, Ithaca, N. Y.
N. H. Winchell, Ann Arbor, Mich.

(Term expires 1895.)

E. A. Smith, University, Ala.
C. D. Walcott, Washington, D. C.

(Term expires 1896.)

F. D. Adams, Montreal, Canada.
I. C. Russell, Ann Arbor, Mich.

*FELLOWS, APRIL, 1894*

* Indicates Original Fellow (see article III of Constitution).

FRANK DAWSON ADAMS, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

TRUMAN H. ALDRICH, M. E., 92 Southern Ave., Cincinnati, Ohio. May, 1889.

HENRY M. AMI, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

ALFRED E. BARLOW, B. A., M. A., Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

GEORGE H. BARTON, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

WILLIAM S. BAYLEY, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

* GEORGE F. BECKER, Ph. D., Washington, D. C.; U. S. Geological Survey.

CHARLES E. BEECHER, Ph. D., Yale University, New Haven, Conn. May, 1889.

ROBERT BELL, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

ALBERT S. BICKMORE, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., N. Y. city; Curator of Anthropology in the American Museum of Natural History. December, 1889.

WILLIAM P. BLAKE, New Haven, Conn.; Mining Engineer. August, 1891.

AMOS BOWMAN, Anacortes, Skagit Co., Wash. State. May, 1889.

EZRA BRAINERD, LL. D., Middlebury, Vt.; President of Middlebury College. December, 1889.

* JOHN C. BRANNER, Ph. D., Menlo Park, Cal.; Professor of Geology in Leland Stanford Jr. University; State Geologist of Arkansas.

ALBERT PERRY BRIGHAM, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

* GARLAND C. BROADHEAD, Columbia, Mo.; Professor of Geology in the University of Missouri.

* WALTER A. BROWNELL, Ph. D., 905 University Ave., Syracuse, N. Y.

HENRY P. H. BRUMELL, Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

* SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoölogy in the State University of Iowa. State Geologist.

HENRY DONALD CAMPBELL, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

MARIUS R. CAMPBELL, U. S. Geological Survey, Washington, D. C. August, 1892.

FRANKLIN R. CARPENTER, Ph. D., Rapid City, South Dakota; Professor of Geology in Dakota School of Mines. May, 1889.

ROBERT CHALMERS, Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

* T. C. CHAMBERLIN, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Henry M. Chance, M. D., Philadelphia, Pa.; Geologist and Mining Engineer. August, 1890.

Clarence Raymond Claghorn, B. S., M. E., 204 Walnut Place, Philadelphia, Pa. August, 1891.

*William B. Clark, Ph. D., Baltimore, Md.; Instructor in Geology in Johns Hopkins University.

*Edward W. Claypole, D. Sc., Akron, O.; Professor of Natural Science in Buchtel College.

Aaron H. Cole, A. M., 5726 Monroe Ave., Hyde Park, Ill. December, 1889.

*Theodore B. Comstock, Tucson, Ariz.; President of the University of Arizona.

*Edward D. Cope, Ph. D., 2102 Pine St., Philadelphia, Pa.; Professor of Geology in the University of Pennsylvania.

*Francis W. Cragin, B. S., Colorado Springs, Col.; Professor of Geology and Natural History in Colorado College.

*Albert R. Crandall, A. M., Milton, Wis.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Malcolm H. Crump, Bowling Green, Ky.; Professor of Natural Science in Ogden College.

Garry E. Culver, A. M., Madison, Wis. December, 1891.

*Henry P. Cushing, M. S., Cleveland, Ohio; Instructor in Geology, Adelbert College.

T. Nelson Dale, Williamstown, Mass.; Geologist, U. S. Geological Survey, Instructor in Geology, Williams College. December, 1890.

*James D. Dana, LL. D., New Haven, Conn.; Professor of Geology in Yale University.

*Nelson H. Darton, United States Geological Survey, Washington, D. C.

*William M. Davis, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

George M. Dawson, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Assistant Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. William Dawson, LL. D., McGill College, Montreal, Canada; Principal of McGill University. May, 1889.

David T. Day, A. B., Ph. D., U. S. Geological Survey, Washington, D. C. August, 1891.

Antonio del Castillo, School of Engineers, City of Mexico, Director of National School of Engineers; Director Geological Commission, Republic of Mexico. August, 1892.

Frederick P. Dewey, Ph. B., 621 F St. N. W., Washington, D. C. May, 1889.

Orville A. Derby, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*Joseph S. Diller, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

*Edwin T. Dumble, Austin, Texas; State Geologist.

Clarence E. Dutton, Major, U. S. A., Ordnance Department, San Antonio, Texas. August, 1891.

* William B. Dwight, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

* George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.

Robert W. Ells, LL. D., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. December, 1888.

* Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

* Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology and Natural History in University of Rochester.

J. C. Fales, Danville, Kentucky; Professor in Centre College. December, 1888.

Eugene Rudolph Faribault, C. E., Geological Survey Office, Ottawa, Canada. August, 1891.

P. J. Farnsworth, M. D., Clinton, Iowa; Professor in the State University of Iowa. May, 1889.

Moritz Fischer, Curator, E. M. Museum, Princeton, N. J. May, 1889.

Sandford Fleming, LL. D., Ottawa, Canada; Civil Engineer. August, 1893.

* Albert E. Foote, M. D., 4116 Elm Ave., Philadelphia, Pa.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* Homer T. Fuller, Ph. D., Worcester, Mass.; Professor of Geology in Worcester Polytechnic Institute.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* Grove K. Gilbert, A. M., United States Geological Survey, Washington, D. C.

Adams C. Gill, A. B., Northampton, Mass. December, 1888.

N. J. Giroux, C. E., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

Charles H. Gordon, M. S., 453 55th St., Chicago, Ill. August, 1893.

Ulysses Sherman Grant, Ph. D., University of Minnesota, Minneapolis, Minn.; Assistant on Geological Survey of Minnesota. December, 1890.

William Stukeley Gresley, Erie, Pa.; Mining Engineer. December, 1893.

* George B. Grinnell, Ph. D., 318 Broadway, New York city.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

* William F. E. Gurley, Springfield, Ill.; State Geologist.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

* Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

* James Hall, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.

Henry G. Hanks, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist. December, 1888.

John B. Hastings, M. E., Boisé City, Idaho. May, 1889.

* ERASMUS HAWORTH, Ph. D., Lawrence, Kansas.
* ROBERT HAY, Box 562, Junction City, Kansas; Geologist, U. S. Department of Agriculture.

C. WILLARD HAYES, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

* ANGELO HEILPRIN, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

CLARENCE L. HERRICK, M. S., 324 Hamilton Ave., North Side, Cincinnati, Ohio; Professor of Geology and Biology in the University of Cincinnati. May, 1889.

* LEWIS E. HICKS, Rangoon, Burma.
* EUGENE W. HILGARD, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

FRANK A. HILL, 208 S. Centre St., Pottsville, Pa.; Geologist in Charge of Anthracite District, Second Geological Survey of Pennsylvania. May, 1889.

* ROBERT T. HILL, B. S., U. S. Geological Survey, Washington, D. C.
* CHARLES H. HITCHCOCK, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

WILLIAM HERBERT HOBBS, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

* LEVI HOLBROOK, A. M., P. O. Box 536, New York city.

CHARLES A. HOLLICK, Ph. B., Columbia College, New York; Instructor in Paleontology. August, 1893.

* JOSEPH A. HOLMES, Chapel Hill, North Carolina; State Geologist and Professor of Geology in University of North Carolina.

MARY E. HOLMES, Ph. D., 201 S. First St., Rockford, Illinois. May, 1889.

* JEDEDIAH HOTCHKISS, 346 E. Beverly St., Staunton, Virginia.
* EDMUND O. HOVEY, Ph. D., American Museum of Natural History, New York city.
* HORACE C. HOVEY, D. D., Newburyport, Mass.
* EDWIN E. HOWELL, A. M., 537 15th St. N. W., Washington, D. C.
* ALPHEUS HYATT, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.

JOSEPH P. IDDINGS, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. WENDELL JACKSON, Ph. B., 44 Broadway, New York city. December, 1888.

THOMAS M. JACKSON, C. E., Morgantown, W. Va.; Professor of Civil and Mining Engineering in West Virginia University. May, 1889.

* JOSEPH F. JAMES, M. S., Department of Agriculture, Washington, D. C.
* LAWRENCE C. JOHNSON, United States Geological Survey, Meridian, Miss.
* WILLARD D. JOHNSON, United States Geological Survey, Washington, D. C.

ALEXIS A. JULIEN, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

EDMUND JÜSSEN, Ph. D., Temple, Carroll Co., Ga. December, 1890.

ARTHUR KEITH, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

* JAMES F. KEMP, A. B., E. M., Columbia College, New York city; Adjunct Professor of Geology.

CHARLES ROLLIN KEYES, A. M., Ph. D., Assistant State Geologist, Des Moines, Iowa. August, 1890.

CLARENCE KING, 18 Wall St., New York city; lately Director of the U. S. Geological Survey, May, 1889.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. May, 1889.

*George F. Kunz, care of Tiffany & Co., 15 Union Square, New York.

Ralph D. Lacoe, Pittston, Pa. December, 1889.

George Edgar Ladd, A. B., A. M., 81 Oxford St., Cambridge, Mass. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Lawrence M. Lambe, Ottawa, Canada; Artist and Assistant in Paleontology and Geological Survey of Canada. August, 1890.

Alfred C. Lane, Ph. D., Houghton, Mich.; Assistant on Geological Survey of Michigan. December, 1889.

Daniel W. Langdon, Jr., A. B., University Club, Cincinnati, Ohio; Geologist of Chesapeake and Ohio Railroad Company. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

*Joseph Le Conte, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

*J. Peter Lesley, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

Frank Leverett, B. S., Denmark, Iowa; Assistant U. S. Geological Survey. August, 1890.

Josua Lindahl, Ph. D., Springfield, Ill. August, 1890.

Waldemar Lindgren, U. S. Geological Survey, Washington, D. C. August, 1890.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. S., Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

Thomas H. McBride, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa County, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., Pittsburg, Pa. August, 1891.

*W J McGee, Washington, D. C.; Bureau of North American Ethnology.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Oliver Marcy, LL. D., Evanston, Cook Co., Ill.; Professor of Natural History in Northwestern University. May, 1889.

Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale University. May, 1889.

Vernon F. Marsters, A. B., Bloomington, Ind.; Associate Professor of Geology in Indiana State University. August, 1892.

P. H. Mell, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

*Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

James E. Mills, B. S., Quincy, Plumas Co., Cal. December, 1888.

Thomas F. Moses, M. D., Urbana, Ohio; President of Urbana University. May, 1889.

*Frank L. Nason, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.

*Henry B. Nason, Ph. D., M. D., LL. D., Troy, N. Y.; Professor of Chemistry and Natural Science in Rensselaer Polytechnic Institute.

*Peter Neff, A. M., 361 Russell Ave., Cleveland, Ohio; Librarian, Western Reserve Historical Society.

Frederick H. Newell, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

William H. Niles, Ph. B., M. A., Cambridge, Mass. August, 1891.

*Edward Orton, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

*Amos O. Osborn, Waterville, Oneida Co., N. Y.

*Horace B. Patton, Ph. D., Golden, Col.; Professor of Geology and Mineralogy in Colorado School of Mines.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

Joseph H. Perry, 176 Highland St., Worcester, Mass. December, 1888.

*William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology and Mining Engineering in Michigan University.

*Franklin Platt, 1319 Walnut St., Philadelphia, Pa.

*Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

William B. Potter, A. M., E. M., St. Louis, Mo.; Professor of Mining and Metallurgy in Washington University. August, 1890.

*John W. Powell, Director of U. S. Geological Survey, Washington, D. C.

*Charles S. Prosser, M. S., Topeka, Kan.; Professor of Geology in Washington College.

*Raphael Pumpelly, U. S. Geological Survey, Newport, R. I.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Heinrich Ries, Ph. B., Fellow in Mineralogy, Columbia College, New York city. December, 1893.

Charles W. Rolfe, M. S., Urbana, Champaign Co., Ill.; Professor of Geology in University of Illinois. May, 1889.

*Israel C. Russell, M. S., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Topeka, Kan. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.

* Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

William B. Scott, M. A., Ph. D., Princeton, N. J.; Professor in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

Alfred R. C. Selwyn, C. M. G., LL. D., Ottawa, Canada; Director of Geological and Natural History Survey of Canada. December, 1889.

* Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

* Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

* Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

James Perrin Smith, M. S., Ph. D., Palo Alto, California; Assistant Professor of Paleontology, Leland Stanford Jr. University. December, 1893.

* John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

* J. W. Spencer, A. M., Ph. D., Atlanta, Georgia.

Joseph Stanley-Brown, Assistant Geologist U. S. Geological Survey; Washington, D. C. August, 1892.

Timothy William Stanton, B. S., U. S. Geological Survey, Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. August, 1891.

* John J. Stevenson, Ph. D., LL. D., University of the City of New York; Professor of Geology in the University of the City of New York.

Ralph S. Tarr, Cornell University, Ithaca, N. Y. August, 1890.

* Asa Scott Tiffany, 901 West Fifth St., Davenport, Iowa.

* James E. Todd, A. M., Vermillion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

* Henry W. Turner, U. S. Geological Survey, Washington, D. C.

Joseph B. Tyrrell, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

* Edward O. Ulrich, A. M., Newport, Ky.; Paleontologist of the Geological Survey of Minnesota.

* Warren Upham, A. B., Assistant Geological Survey of Minnesota; Minneapolis, Minn.

* Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist U. S. Geological Survey.

* Anthony W. Vogdes, Alcatraz Island, San Francisco, Cal.; Captain Fifth Artillery, U. S. Army.

Charles Wachsmuch, M. D., Burlington, Iowa. May, 1889.

* Marshman E. Wadsworth, Ph. D., Houghton, Mich.; State Geologist; Director of Michigan Mining School.

* Charles D. Walcott, U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

THOMAS C. WESTON, Ottawa, Canada, Assistant Curator Geological Survey Department Museum. August, 1893.

DAVID WHITE, U. S. National Museum, Washington, D. C.; Assistant Paleontolo gist U. S. Geological Survey, Washington, D. C. May, 1889.

*ISRAEL C. WHITE, Ph. D., Morgantown, W. Va.

*CHARLES A. WHITE, M. D., U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

JOSEPH FREDERICK WHITEAVES, Ottawa, Canada; Paleontologist and Assistant Director Geological Survey of Canada. December, 1892.

*ROBERT P. WHITFIELD, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

CHARLES L. WHITTLE, West Medford, Mass.; Assistant Geologist U. S. Geological Survey. August, 1892.

*EDWARD H. WILLIAMS, JR., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

*GEORGE H. WILLIAMS, Ph. D., Johns Hopkins University, Baltimore, Md.; Professor of Inorganic Geology in Johns Hopkins University.

*HENRY S. WILLIAMS, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

*SAMUEL G. WILLIAMS, Ph. D., Ithaca, N. Y.; Professor in Cornell University.

BAILEY WILLIS, U. S. Geological Survey, Washington, D. C. December, 1889.

*HORACE VAUGHN WINCHELL, 1306 S. E. 7th St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.

*NEWTON H. WINCHELL, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

*ARTHUR WINSLOW, B. S., Jefferson City, Mo.; State Geologist.

JOHN E. WOLFF, Ph. D., Harvard University, Cambridge, Mass.; Assistant Professor in Petrography, Harvard University. December, 1889.

ROBERT SIMPSON WOODWARD, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

ALBERT A. WRIGHT, A. B., Ph. B., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

*G. FREDERICK WRIGHT, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

LORENZO G. YATES, M. D., Los Angeles, Cal. December, 1889.

## *FELLOWS DECEASED*

*Indicates Original Fellow (see article III of Constitution)

*CHARLES A. ASHBURNER, M. S., C. E. Died December 24, 1889.

*J. H. CHAPIN, Ph. D., Meriden, Conn. Died March 14, 1892.

GEORGE H. COOK, Ph. D., LL. D. Died September 22, 1889.

DAVID HONEYMAN, D. C. L. Died October 17, 1889.

THOMAS STERRY HUNT, D. Sc., LL. D. Died February, 1892.

*JOHN S. NEWBERRY, M. D., LL. D. Died December 7, 1892.

*RICHARD OWEN, LL. D. Died March 24, 1890.

*J. FRANCIS WILLIAMS, Ph. D. Died November 9, 1891.

*ALEXANDER WINCHELL, LL. D. Died February 19, 1891.

*Summary.*

| | |
|---|---|
| Deceased Fellows | 9 |
| Original Fellows | 98 |
| Elected Fellows | 122 |
| Membership | 220 |

# CONSTITUTION AND BY-LAWS.

## PREAMBLE.

The Fellows of The Geological Society of America, organized under the provisions of the Constitution approved at Cleveland, Ohio, August 15, 1888, and adopted at Ithaca, New York, December 27, 1888, hereby ordain the following revised Constitution :

## CONSTITUTION.

### Article I.

#### NAME.

This Society shall be known as The Geological Society of America.

### Article II.

#### OBJECT.

The object of this Society shall be the promotion of the Science of Geology in North America.

### Article III.

#### MEMBERSHIP.

The Society shall be composed of Fellows, Correspondents and Patrons.

1. Fellows shall be persons who are engaged in geological work or in teaching geology and resident in North America.

Fellows admitted without election under the Provisional Constitution shall be designated as Original Fellows on all lists or catalogues of the Society.

2. Correspondents shall be persons distinguished for their attainments in Geological Science and not resident in North America.

3. Patrons shall be persons who have bestowed important favors upon the Society.

4. Fellows alone shall be entitled to vote or hold office in the Society.

### Article IV.

#### OFFICERS.

1. The Officers of the Society shall consist of a President, First and Second Vice-Presidents, a Secretary, a Treasurer, and six Councilors.

These officers shall constitute an Executive Committee, which shall be called the Council.

2. The President shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Constitution and By-Laws to be faithfully carried into effect.

3. The First Vice-President shall assume the duties of President in case of the absence or disability of the latter. The Second Vice-President shall assume the duties of President in case of the absence or disability of both the President and First Vice-President.

4. The Secretary shall keep the records of the proceedings of the Society, and a complete list of the Fellows, with the dates of their election and disconnection with the Society. He shall also be the secretary of the Council.

The Secretary shall coöperate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing and mailing of circulars, blanks and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution, under the direction of the Council.

The Secretary, unless other provision be made, shall also act as Editor of the publications of the Society, and as Librarian and Custodian of the property.

5. The Treasurer shall have the custody of all funds of the Society. He shall keep account of receipts and disbursements in detail, and this shall be audited as hereinafter provided.

6. The Society may elect an Editor to supervise all matters connected with the publication of the transactions of the Society under the direction of the Council, and to perform the duties of Librarian until such time as, in the opinion of the Council, the Society should make that an independent office.

7. The Council is clothed with executive authority and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. They shall receive nominations for Fellows, and, on approval by them, shall submit such nominations to the Society for action. They shall have power to fill vacancies *ad interim* in any of the offices of the Society.

8. *Terms of Office.*—The President and Vice-Presidents shall be elected annually, and shall not be eligible to re-election more than once until after an interval of three years after retiring from office.

The Secretary and Editor shall be eligible to re-election without limitation.

The term of office of the Councilors shall be three years; and these officers shall be so grouped that two shall be elected and two retire each year. Councilors retired shall not be re-eligible till after the expiration of a year.

## Article V.

### VOTING AND ELECTIONS.

1. All elections shall be by ballot. To elect a Fellow, Correspondent or Patron, or impose any special tax, shall require the assent of nine-tenths of all Fellows voting.

2. Voting by letter may be allowed.

3. *Election of Fellows.*—Nominations for fellowship may be made by two Fellows according to a form to be provided by the Council. One of these Fellows must be personally acquainted with the nominee and his qualifications for membership. The Council will submit the nominations received by them, if approved, to a vote of the Society in the manner provided in the By-Laws. The result may be an-

nounced at any stated meeting; after which notices shall be sent out to Fellows elect.

4. *Election of Officers.*—Nominations for office shall be made by the Council. The nominations shall be submitted to a vote of the Society in the same manner as nominations for fellowship. The results shall be announced at the Annual Meeting; and the officers thus elected shall enter upon duty at the adjournment of the meeting.

### Article VI.

#### MEETINGS.

1. The Society shall hold at least two stated meetings a year—a Summer Meeting at the same locality and during the same week as the annual meeting of the American Association for the Advancement of Science—and a Winter Meeting. The date and place of the Winter Meeting shall be fixed by the Council, and announced by circular each year within a month after the adjournment of the Summer Meeting. The program of each Meeting shall be determined by the Council, and announced beforehand, in its general features. The details of the daily sessions shall also be arranged by the Council.

2. The Winter Meeting shall be regarded as the Annual Meeting. At this, elections of Officers shall be declared, and the officers elect shall enter upon duty at the adjournment of the Meeting.

3. Special Meetings may be called by the Council, and must be called upon the written request of twenty Fellows.

4. Stated Meetings of the Council shall be held coincidently with the Stated Meetings of the Society. Special meetings may be called by the President at such times as he may deem necessary.

5. *Quorum.*—At meetings of the Society a majority of those registered in attendance shall constitute a quorum. Five shall constitute a quorum of the Council.

### Article VII.

#### PUBLICATION.

The serial publications of the Society shall be under the immediate control of the Council.

### Article VIII.

#### AMENDMENTS.

1. This Constitution may be amended at any annual meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting.

2. By-laws may be made or amended by a majority vote of the Fellows present and voting at any annual meeting, provided that printed notice of the proposed amendment or by-law shall have been given to all Fellows at least three months before the meeting.

## BY-LAWS.

### Chapter I.

#### OF MEMBERSHIP.

1. No person shall be accepted as a Fellow unless he pay his initiation fee, and the dues for the year, within three months after notification of his election. The

initiation fee shall be ten (10) dollars and the annual dues ten (10) dollars, the latter payable on or before the annual meeting in advance; but a single prepayment of one hundred (100) dollars shall be accepted as commutation for life.

2. The sums paid in commutation of dues shall be covered into the Publication Fund.

3. An arrearage in payment of annual dues shall deprive a Fellow of the privilege of taking part in the management of the Society and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

4. Any person eligible under Article III of the Constitution may be elected Patron upon the payment of one thousand (1,000) dollars to the Publication Fund of the Society.

## Chapter II.

### OF OFFICIALS.

1. The President shall countersign, if he approves, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

2. The Secretary, until otherwise ordered by the Society, shall perform the duties of Editor, Librarian and Custodian of the property of the Society.

3. The Society may elect an Assistant Secretary.

4. The Treasurer shall give bonds, with two good sureties approved by the Council, in the sum of five thousand dollars, for the faithful and honest performance of his duties and the safe-keeping of the funds of the Society. He may deposit the funds in bank at his discretion, but shall not invest them without authority of the Council. His accounts shall be balanced as on the thirtieth day of November of each year.

5. In the selection of Councilors the various sections of North America shall be represented as far as practicable.

6. The minutes of the proceedings of the Council shall be subject to call by the Society.

7. The Council may transact its business by correspondence during the intervals between its stated meetings; but affirmative action by a majority of the Council shall be necessary in order to make action by correspondence valid.

## Chapter III.

### OF ELECTION OF MEMBERS.

1. Nominations for fellowship may be proposed at any time on blanks to be supplied by the Secretary.

2. The *form* for the nomination of Fellows shall be as follows:

In accordance with his desire, we respectfully nominate for Fellow of the Geological Society of America:

Full name; degrees; address; occupation; branch of Geology now engaged in, work already done and publications made.

(Signed by at least two Fellows.)

The form when filled is to be transmitted to the Secretary.

3. The Secretary will bring all nominations before the Council, at either the Winter or Summer Meeting of the Society, and the Council will signify its approval or disapproval of each.

4. At least a month before one of the stated meetings of the Society the Secretary will mail a printed list of all approved nominees to each Fellow, accompanied by such information as may be necessary for intelligent voting; but an informal list of the candidates shall be sent to each Fellow at least two weeks prior to distribution of the ballots.

5. The Fellows receiving the list will signify their approval or disapproval of each nominee, and return the lists to the Secretary.

6. At the next stated meeting of the Council the Secretary will present the lists and the Council will canvass the returns.

7. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for fellowship.

8. At the next stated meeting of the Society the Council shall declare the results.

9. Correspondents and Patrons shall be nominated by the Council, and shall be elected in the same manner as Fellows.

## Chapter IV.

### OF ELECTION OF OFFICERS.

1. The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket.

2. The list shall be mailed to the Fellows, for their information, at least 40 days before the Annual Meeting. Any five Fellows may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least 20 days before the Annual Meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows at least 15 days before the Annual Meeting.

3. The Fellows will send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the winter meeting of the Council, the Secretary will bring the returns of ballots before the Council for canvass, and during the winter meeting of the Society the Council shall declare the result.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such winter meeting proceed to make an election for such office from the two candidates having the highest number of votes.

## Chapter V.

### OF FINANCIAL METHODS.

1. No pecuniary obligation shall be contracted without express sanction of the Society or the Council. But it is to be understood that all ordinary, incidental and running expenses have the permanent sanction of the Society, without special action.

2. The creditor of the Society must present to the Treasurer a fully itemized bill, certified by the official ordering it, and approved by the President. The Treasurer shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

3. At each annual meeting, the President shall call upon the Society to choose two Fellows, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as

specified in the By-Laws, Chapter II, Clause 4. The Auditors shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action.

## Chapter VI.

### OF PUBLICATIONS.

1. The publications are in charge of the Council and under its control.
2. One copy of each publication shall be sent to each Fellow, Correspondent and Patron, and each author shall receive thirty (30) copies of his memoir.

## Chapter VII.

### OF THE PUBLICATION FUND.

1. The Publication Fund shall consist of moneys paid by the general public for publications of the Society, of donations made in aid of publication, and of the sums paid in commutation of dues, according to the By-Laws, chapter I, clause 2.
2. Donors to this fund, not Fellows of the Society, in the sum of two hundred dollars, shall be entitled, without charge, to the publications subsequently appearing.

## Chapter VIII.

### OF ORDER OF BUSINESS.

1. The Order of Business at Winter Meetings shall be as follows:
   (1) Call to order by the presiding officer.
   (2) Introductory ceremonies.
   (3) Report of the Council (including reports of the officers).
   (4) Appointment of the Auditing Committee.
   (5) Declaration of the vote for officers, and election by the meeting in case of failure to elect by the Society through transmitted ballots.
   (6) Declaration of the vote for Fellows.
   (7) Deferred business.
   (8) New business.
   (9) Announcements.
   (10) Necrology.
   (11) Reading of scientific papers.
2. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.
3. At the Summer Meeting the items of business under numbers (3), (4), (5), (10) shall be omitted.
4. At any Special Meeting the order of business shall be numbers (1), (2), (3), (9), followed by the special business for which the meeting was called.

# RULES RELATING TO PUBLICATION.

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ADOPTED BY THE COUNCIL APRIL 21, 1891

(*Revised April 30, 1894*)

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## General Provisions.

Section 1. The Council shall annually appoint from their own number a Publication Committee, consisting of the Secretary and two others, whose duties shall be to determine the disposition of matter offered for publication, except as provided in Section 17; to determine the expediency, in view of the financial condition of the Society, of publishing any matter accepted on its merits; to exercise general oversight of the matter and manner of publication; to determine the share of the cost of publication (including illustrations) to be borne by the author when it becomes necessary to divide cost between the Society and the author; to adjudicate any questions relating to publication that may be raised from time to time by the Editor or by the Fellows of the Society; and in general to act for the Council in all matters pertaining to publication. (Constitution, Art. IV, 7; Art. VII; By-laws, chap. VI.)

2. The duties of the Editor are to receive material offered for publication; to examine the same and submit it to the Publication Committee, with estimates as to cost of publishing; to publish all material accepted for that purpose by the Council or Publication Committee; to revise proofs in connection with authors; to prepare lists of contents and general indices; to audit bills for printing and illustrating; and to perform all other duties connected with publication which are not assigned to other officers. (Constitution, Art. IV, 6; Rules, Sec. 16.)

3. The duties of the Secretary include the preparation of a record of the proceedings of each meeting of the Society in form for publication, and the custody, distribution, sale, exchange or other authorized disposition of the publications. (Constitution, Art. IV, 4; By-laws, chap. II, 2.)

4. Special committees may be appointed by the Council or the Publication Committee to examine and report upon any matter offered for publication. (Rules, Sec. 16.)

### The Bulletin.

5. The Society shall publish a serial record of its work entitled "Bulletin of the Geological Society of America."

6. The Bulletin shall be published, for immediate distribution, in covered parts or brochures, consecutively paged for each volume. The brochures shall be designated by volume numbers and limiting pages, and each shall bear a special title setting forth the contents and authorship, the seal and imprint of the Society and the date of publication (Rules, Sec. 27). The Bulletin shall also be published in complete volumes, and each volume shall comprise the issue of a calendar year.

7. The brochures shall be classed as memoir brochures and brochures of proceedings.

8. Each memoir brochure shall consist normally of a single memoir or article, either accompanied by discussion or not; it may consist exceptionally of two or more memoirs where the subject-matter is closely related.

9. The proceedings of the annual, summer and special meetings of the Society, prepared by the Secretary (including short papers, abstracts, etc.), shall be published as separate brochures as soon as may be after these meetings.

10. The proceedings of the annual meeting shall form the closing portion of the volume for the year.

11. The brochure containing the proceedings of the annual meeting shall contain also an index to the volume, paged consecutively with the body of the volume; and it shall be accompanied by a volume title-page and lists of contents and illustrations, together with lists of the publications of the Society and such other matter as may be deemed necessary by the Publication Committee, all arranged under a separate Roman pagination.

#### *Matter of the Bulletin.*

12. The matter published in the Bulletin shall comprise (1) communications presented at meetings by title or otherwise; (2) communications or memoirs not presented before the Society; (3) abstracts of papers read before the Society, prepared or revised for publication by authors; (4) reports of discussions made before the Society, prepared or revised for publication by authors; (5) proceedings of the meetings of the Society prepared by the Secretary; (6) plates, maps and other illustrations necessary for the proper understanding of communications; (7) lists of Officers and Fellows, Constitution, By-laws, resolutions of permanent character, rules relating to procedure, to publication and to other matters, etc.; and (8) indices, title-pages and lists of contents for each volume.

13. Communications making sixteen or more printed pages of text, including figures, shall be published as memoir-brochures. Communications making less than sixteen printed pages may be included in the proceedings brochures or published as memoir brochures, at the option of the individual authors; but in the latter

case the number of pages shall not be less than eight, unless authorized by the Publication Committee, and the additional expense for brochure covers and distribution may be assessed on the authors.

14. Abstracts, reports of discussion, or other matter purporting to emanate from any author shall not be published unless it has been either prepared or revised by the author.

15. Manuscript designed for publication in the Bulletin must be complete as to copy for text and illustration, unless by special arrangement between the author and the Council or Publication Committee; it must be perfectly legible (preferably typewritten) and preceded by a table of contents (Rules, Sec. 20). The cost of any necessary revision of copy or reconstruction of illustrations shall be assessed upon the author.

16. The Editor shall examine matter designed for publication, and shall prepare an itemized estimate of the cost of publication and convey the whole to the Publication Committee. The Publication Committee shall then scrutinize the communication with reference, first, to relevancy; second, to scientific value; third, to literary character, and, fourth, to cost of publication, including revision. For advice with reference to the relevancy, scientific value and literary character of any communication the Publication Committee may refer it to a special committee of their own number or of the Society at large or may call to their aid from outside one or more experts. Questions of disagreement between the Editor and authors shall be referred to the Publication Committee, and appeal may be taken to the Council.

17. Communications from non-fellows shall be published only by specific authority from the Council.

18. Communications from Fellows not presented at regular meetings of the Society shall be published only upon unanimous vote of the Publication Committee, except by specific authority from the Council.

19. Matter offered for publication becomes thereby the property of the Society, and shall not be published elsewhere prior to publication in the Bulletin, except by consent of the Publication Committee.

*Details of the Bulletin.*

20. The matter of each memoir published as a separate brochure shall be classified by subjects, and the classification suitably indicated by sub-titles; and a list of contents shall be arranged with reference to the sub-titles; and such brochure may, at the option of the Publication Committee, contain an alphabetical index, provided the same be prepared by the author and paid for by him.

21. Proofs of letter-press, and, when necessary, of illustrations, shall be submitted to authors whenever practicable; but printing shall not be delayed by reason of absence or incapacity of authors more than one week beyond the time ordinarily required for the transmission of mails. Complete proofs of the proceedings of meetings shall be sent to the Secretary; and proofs of short papers and

abstracts contained therein and exceeding one-half page in length shall be sent also to authors. (Rules, Sec. 14.)

22. The cost of proof correction in excess of five per cent. on the cost of printing may be charged to authors.

23. Unless the author of a memoir objects thereto the discussion upon his communication shall be printed as the closing part of the brochure, with a suitable reference in the list of contents. In case the author objects to this arrangement, the discussion shall be printed in the proceedings.

24. The author of each memoir printed in brochure form shall receive thirty copies without charge, and shall be authorized to order through the Editor any edition of exactly similar brochures at cost of paper, press-work and binding; and no author's separates of the memoirs published as brochures shall be issued except in this regular form.

25. Authors of papers, abstracts, etc., in the proceedings brochure shall have the privilege of ordering, through the Editor, at their own cost for paper, press-work, binding and necessary composition, any number of separate copies, provided these separates bear the original pagination and a printed reference to the serial and volume from which they are extracted.

26. The Editor shall keep a record of all publications issued wholly or in part under the auspices of the Society, whether the same be authors' editions of the memoir brochures, authors' extracts from proceedings, or any other matter printed from type originally composed for the Bulletin.

*Directions to Printer.*

27. Each brochure of the Bulletin shall begin, under its proper title, on an odd-numbered page bearing at its head the title of the serial, the volume number, the limiting pages, the plates, and the date of publication, together with a list of contents; each brochure shall be accompanied by the illustrations pertaining to it, the plates numbered consecutively for the volume.

28. Each brochure shall be enclosed in a cover bearing at the head of its title-page the title of the serial, the volume number, the limiting pages, and the numbers of the contained plates; in its upper-central part a title indicating the contents and authorship; in its lower-central part the seal of the Society; and at the bottom the imprint of the Society. Volume covers shall correspond to brochure covers, with proper volume designation on side and back.

29. The bottom of each signature and each initial page will bear a signature mark giving an abbreviated title of the serial, the volume, and the year; and every page (except volume title-page) shall be numbered, the initial and sub-title pages in parentheses at bottom.

30. The page-head titles shall be: on even-numbered pages, name of author and catch title of paper; on odd-numbered pages, catch title to contents of page.

31. The date of publication of each brochure shall be the day upon which the last form is locked and put upon the press.

32. The type used in printing the Bulletin shall be as follows: For memoirs, body, long primer, 6-to-pica leads; extracts, brevier, 8-to-pica leads; foot-notes, nonpareil, set solid; titles, long primer caps, with small caps for author's name; sub-titles, long primer caps, small caps, italic, etc., as far as practicable; for designation of cuts, nonpareil caps and italics, and for legends, nonpareil, Roman, set solid; for lists of contents of brochures, brevier, 6-to-pica leads, a new line to an entry, running indentation; for volumes, the same, except 4-to-pica leads and names of authors in small caps; for indices, nonpareil, set solid, double column, leaders, catch words in small caps, with spaces between initial letters. For serial titles, on initial pages, brevier block caps, with corresponding small caps for volume designation, etc.; on covers, the same, except for page heads long primer caps; for serial designation, long primer; for brochure designation, pica caps; special title and author's name, etc., long primer and brevier caps; no frame on cover. No change in type shall be made to adjust matter to pages.

33. Volumes, plates, and cuts in text shall be numbered in Arabic; Roman numeration shall be used only in signature marks, and in paging the lists of contents, etc., arranged for binding at the beginning of the volume.

34. Imprimatur of Editor, on volume title-page; imprimatur of Council and Publication Committee, on obverse of volume title-page; imprimatur of Secretary, on initial pages and covers of brochures of proceedings. Printer's card, in fine type on obverse of title-page.

35. The paper shall be for body of volume, 70 lbs. toned paper, folding to 16 x 25 centimeters; for plates, good quality plate paper, smooth-surfaced, white, cut to 6½ x 10 inches for single plates; for covers smooth-surfaced, fine quality 100 lbs. light-buff manilla paper.

36. The sheets of the brochures, after folding and gathering, shall be stitched with thread; single page plates shall be stitched with the sheets of the brochure to which they pertain; folding plates may be either gummed or stitched (mounted on stubs if necessary); covers shall be gummed.

*Edition and Distribution.*

37. The regular edition shall be 750 copies for the Society, and 30 copies for authors. In case two or more authors contribute to a memoir brochure, the edition of that brochure shall be enlarged so as to give each author thirty copies. (By-laws, chap. VI, 2.)

38. Of the 750 copies printed for the Society, a number exceeding by ten the number required for immediate distribution shall be bound as brochures; the remainder shall be gathered into volumes.

39. Each brochure shall be forwarded promptly on publication to Fellows, Correspondents and Patrons, and to such other regular recipients as shall elect that mode of distribution. On completion of a volume it shall be forwarded to other regular recipients.

40. Of the undistributed residue 100 copies shall be reserved to be sold to Fellows subsequently elected; the remainder shall be held for sale.

41. The Bulletin shall be sent free to Fellows of the Society not in arrears for dues more than one year, to Correspondents and Patrons, and also to exchanging institutions. (By-laws, chap. I, 3.)

42. The price of the Bulletin shall be as follows: Volumes to Fellows at an advance of about fifty per cent on the cost (including incidentals, distribution, etc.), the amount being a multiple of fifty cents. (The price to Fellows, of published volumes, is as follows, prepaid: Vol. 1, \$4.50; Vol. 2, \$4.50; Vol. 3, \$4.00; Vol. 4, \$3.50; Vol. 5, \$4.00.) The fixed price to libraries and institutions is \$5 per volume, and the same to individuals residing outside of North America; to non-fellows in North America, \$10. The price of each brochure shall be a multiple of five cents, and shall be, to Fellows, an advance on cost of about 150 per cent, and to the public, an advance on cost of about 400 per cent. (The prices of brochures may be found in the front of each volume.)

# INDEX TO VOLUME 5.